Risk Benefit Analysis of Large Scale Methods of Generating Electricity

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SUMMARY

Objectives

Large scale power generation from coal, nuclear and hydel sources have health, social and eco-system impacts. Though society pays a cost for these impacts, they are generally not reflected in the cost of power generated. The objective of this study is to provide a holistic view by including these costs, to the extent possible, with the conventional costs. Since impacts are partly site-specific, the exercise is carried out for the Bhakra Nangal hydroelectric project in Himachal Pradesh and the Indraprastha coal based power plant located at New Delhi. For the nuclear option a standardised 235MW CANDU reactor (similar to MAPS) is considered.

Methodology

The impacts are largely directed on natural systems (humans, flora and fauna, etc.) and therefore it is extremely difficult to assign an absolute value to them. However, by defining certain limits to the magnitude of impacts that are allowable, it is possible to provide a reasonable range of values. For instance, if the number of people displaced due to a hydro project is within levels that can be completely rehabilitated including to an extent the intangible elements (such as keeping the community together), then the residual (impact) would be fairly low and a reasonable range for this can be obtained. A similar approach has been used for

computing a range for forest loss. For thermal power projects, based on the concentration levels (uncontrolled) and on the existing ambient pollutant levels, a decision can be made whether to install control equipment [applicable for oxides of sulphur and nitrogen (SO_x and NO_x respectively) since the use of electostatic precipitators (ESP) for the control of particulate matter is mandatory]. For nuclear power generation, international estimates for decommissioning and long term waste disposal are used to define the lower bounds.

Results and Conclusions

Results indicate the cost of generating 1 kWh ranges from Rs 0.18-0.24 for the Bhakra Nangal Hydroproject; Rs 2.04-2.89 for a 235 MW CANDU nuclear plant and Rs 1.8-2.32 for the coal based Indraprastha Power Station. As seen from the case studies, Bhakra Nangal hydroelectric project is the most economic option, followed by the coal based Indraprastha power station, and lastly the nuclear option. While the lower bound for the hydro option does not include social and environmental costs, the upper bound includes a liberal estimation for both. In the case of coal based power generation, the most likely estimate tends towards the lower bound (which includes an ESP but no additional control equipment) since SO_x and NO_x emissions from the plant are low (averaging less than 5ug/m^3 in most of the populated zones for any season). The upper bound represents an extreme case of installing flue gas desulphurisation (FGD) equipment and

a selective catalytic reduction (SCR) equipment. These figures however, do not reflect the costs of land and water pollution emanating from ash disposal. For the nuclear option, the most likely option tends towards the upper bound since this represents existing operating practice. The lower bound serves more as a target (based on DAE performance criterion) that can only be achieved with better performance.

Recommendations

Hydro: It is imperative that upper limits to the number of people displaced and the magnitude of forest loss from a project be established.

Coal: Ash utilisation needs an immediate thrust. Currently technologies for manufacturing flyash based products are more expensive than established ones and therfore research in developing cost effective technologies needs to be accelerated.

Careful siting of a plant may also reduce the need for installing additional pollution control equipment. This factor should also be studied along with the other factors that govern plant siting.

Also standards for heavy metals in ash dump effluents need to be set.

Nuclear: Nuclear is the most expensive and therefore it is imperative to improve its performance, for it to be economically viable. Further, two issues that would need to be resolved in the coming years are decommissioning and long term waste disposal.

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CHAPTER I

Introduction

There are no options for large scale generation of electricity that are without drawbacks. Coal, hydro and nuclear power plants have adverse social and environmental effects. These effects vary widely depending upon the type of power plant. During normal operation of coal plants, large quantities of ash (especially in the case of Indian coal) not only require large areas of land for disposal, but also run-offs from it result in deterioration of the neighbouring surface and ground water quality. Emissions from the stack such as particulates, sulphur oxides and nitrogen oxides, in addition to causing health damage to human beings also affect plant and animal life adversely. Heated water from the cooling system, discharged into the river or lake (main source), affects the physical, chemical and biological characteristics of the water in the main source, thereby impairing the aquatic ecosystem.

The operation of nuclear plants result in low level radiation, water pollution ("thermal - due to discharge of cooling water into the main source) and waste disposal problems. The health effects of low level radiation is drawing increasing attention today. Recent studies have shown that previously considered safe levels are questionable with potential health hazards occurring at doses less than 10 mSv. Disposal of radioactive wastes remains a problem and of course the greatest underlying hazard from nuclear plants is the event of an accident (due to external causes such as earthquakes, floods, air

crashes, etc. or due to internal causes such as component failure, human error, etc.) that is accompanied by a large release of radioactivity, the impact of which may be catastrophic.

In the case of hydro, the development of large dams can lead to submergence of large areas which may result in the displacement of a large number of people from their homeland and the loss of the existing ecosystem. Again, the event of a dam collapse (due to manmade or natural causes) can have serious consequences in terms of loss of life and property in the downstream area.

A pictorial view of the external effects arising from operating coal, hydro and nuclear power plants are shown in Figure 1.1. The impact consequences can be grouped together on the basis of health, social and ecosystem effects.

In the long run, society bears a burden of these impacts in various ways, such as increased costs of health treatment, rehabilitation, etc. Although these impacts are a direct consequence of the power plants, decision making in the past has tended to ignore these externalities, the only decision variable being the `standard' cost of producing electricity based on the capital and operating costs of generation. Since this provides only a partial assessment, it is imperative to develop a framework that would also include the environmental and social impacts so as to provide a more holistic evaluation for each mode of generation and a

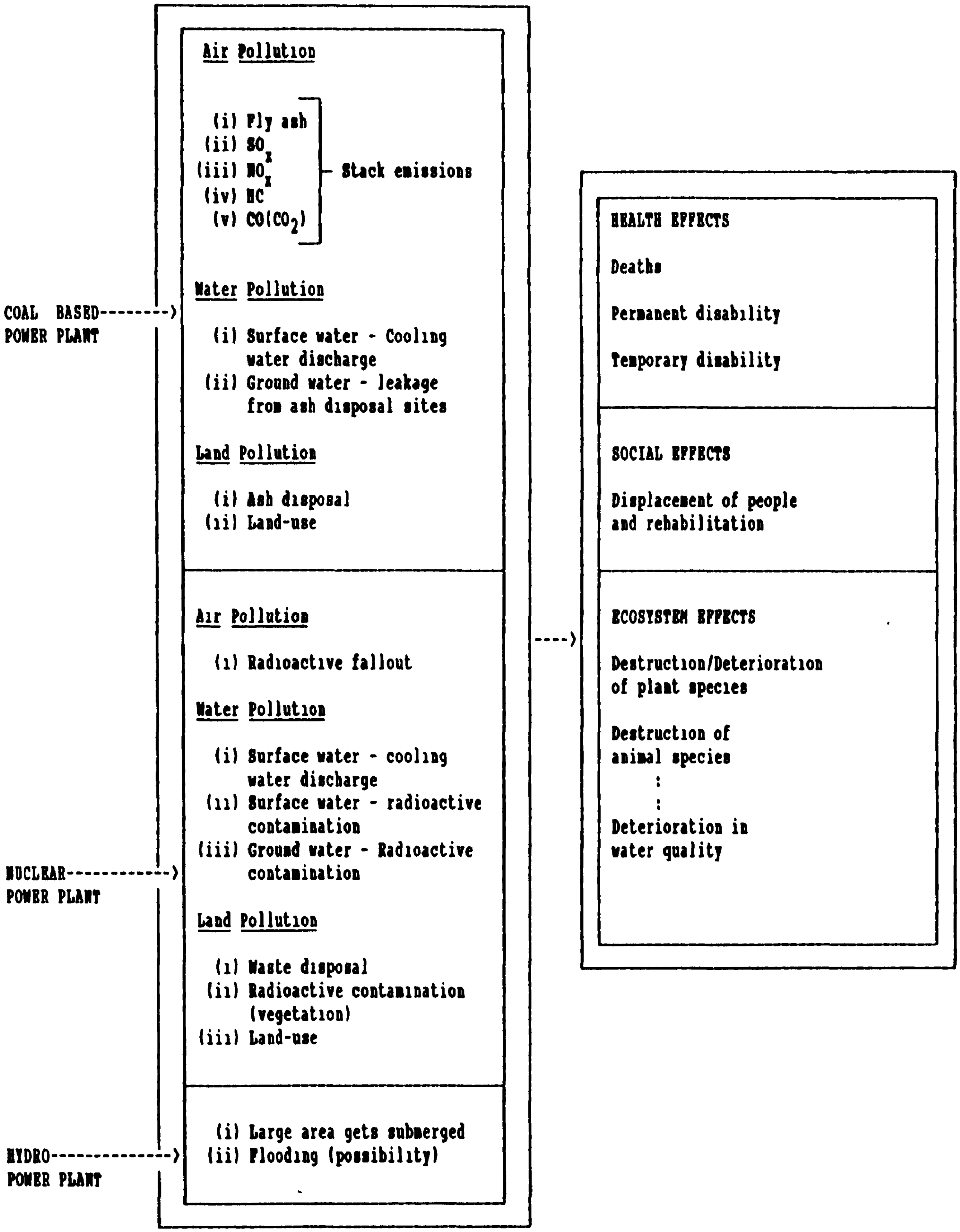


Figure 1.1: Impacts of electric supply from coal, nuclear and hydro power plants

robust basis for their comparison. The objective of this study is to develop such a framework for comparing coal, nuclear and hydroelectric forms of generation.

Since monetary costs are the universal basis for decision-making, it would be convenient if the impacts are translated into costs and added to the traditional cost of generation. However, in doing so, a host of difficulties arise.

Placing monetary values on damage to human health and on the ecosystem is an extremely difficult task. Since perceptions differ among people, the value assigned can differ widely. With reference to valuing health impacts Hufschmidt et al. (1983) state,

> ".. it is difficult to value human life and damages to human health, because even when the effects of air pollution on human health are known, there is no general agreement among economists on how to value damages to health."

Consider the case for evaluating forest loss. Forests provide a multitude of services ranging from the provision of forest products to ensuring habitation on this planet. Placing a monetary value on this resource that would adequately reflect all these services is almost an impossible task, and even if this was possible, would the estimates be robust enough, and therefore, of practical use ?

The above difficulties are also true in valuing other social and eco-system impacts. However, complete economic valuation of externalities is not possible. Recognising this fact, McDonald (1990) uses an approach,

where each decision choice is described by a cost and an environmental score. The integral components of the costs are (i) standard project costs and (ii) economic evaluation of the impacts to the extent possible. The environmental score is calculated for only those impacts that are not costed. This is done by using a standard Environmental Impact Assessment (EIA) technique [see Canter (1977)] where impacts are quantified across a uniform scale (say 0 to 1), the aggregation across impacts being done by assigning suitable weights to the individual scores to arrive at a total score. This approach however, does not permit a direct comparison across the various alternatives. To elaborate, how would one compare two technologies, one with a lower cost and a high environmental score, with the other having the opposite cost and environmental features. Additionally, the technique involves quantification and weighting of each environmental impact, both of which can be very subjective.

In light of the above discussion, even if complete economic evaluation (in the form of a point estimate) is not possible, an attempt should be made to develop reasonable ranges for cost estimates. This perhaps is possible if one lays down a set of conditions/boundary conditions, within which a reasonable estimation of the impacts is permissible. The following sections discuss the application of these conditions for hydro, coal and nuclear plants.

Hydro: The two major issues are large scale displacement and forest submergence. For some hydroprojects, displacement can be very large (over 50,000 people). Even with a liberal rehabilitation package, it is not possible to rehabilitate such a large number of people in terms of land and other resource requirements. Coupled with administrative inefficiencies and corruption that are prevalent, rehabilitation is seldom complete. This leads to a large degree of discontent amongst the oustees. Often lives can be very severely affected as in the case of tribals who are displaced from their forest homeland and have to change their way of life, without the necessary support from the government. Even attempting to place a value under such a situation is absurd, the issue going much beyond project economics. It is therefore essential to establish an upper limit to the number of people that can be displaced by a project. Given such an upper limit, and with the current trend of liberal rehabilitation packages the degree of discontent would be fairly low, the impact of which can be studied by conducting a simple sensitivity analysis around the costs for rehabilitation (say in the range of 100-500%) and seeing this impact on the cost of generation. Currently, the Ministry of Environment and Forests evaluates rehabili-tation packages by scaling the rehabilitation costs by a factor of 1.5.

A similar boundary needs to be set for forest loss. Given the level of forests in the region/country, an

upper limit needs to be defined to the amount of forest loss that is acceptable. This limit would depend upon the level of critical forest cover defined for the region/country. This upper limit would act as a constraint around which the projects should be designed. Given this permissible level, a range of cost-estimates for environmental services cost can be determined. For example, a likely range could begin from 100%-500% of the value of timber. Studies in the past have estimated cost of certain environmental services to range upto approximately 100% of the value of timber.

Coal: Consider health impacts from coal based power plants. Where pollution control equipment is mandatory, the health damage will generally be on the lower side, if not minimal. This would apply in the case of electrostatic precipitators (ESP) for the control of particulates. For oxides of sulphur and nitrogen (SO_x and NO_x) installation of flue gas desulphurisation (FGD) equipment and the use of selective catalytic reduction (SCR) techniques or the use of low NO_x burners are not mandatory. In these cases, based on the level of uncontrolled concentration profiles in the vicinity of the plant and <u>conservative</u> allowable limits, the cost of the pollution control equipment can be used as a measure of the externality. The residual under such a situation would be minimal or atleast on the lower side.

Nuclear: The case of a nuclear power plant differs from the coal plant in that there are no additional pollution control equipment as such that can be added. The design of the plant ensures that normal releases of radioactivity are well within the limits specified by the International Commission for Radiological Protection. Hence, the capital costs should reflect the complete costs, as the externalities are minimal. The two unresolved issues are decommissioning and long term waste disposal. Available international estimate have been used to account for these issues. These should probably be considered as lower bounds, in light of the fact that no plant in India has been decommissioned yet.

Taking into account the above considerations, an exercise has been undertaken for studying the Bhakra Nangal Hydroelectric Project, the Indraprastha Coal Based Power Station in Delhi and a standard nuclear (CANDU) power plant (similar to MAPS). Results indicate that the cost of generating 1 kWh varies from Rs 0.18-0.24 for Bhakra Nangal, Rs 1.8-2.32 for Indraprastha Power Station, and Rs 2.04-2.89 for the nuclear power plant.

Chapter 2 discusses in detail the hydro option for generating electricity. In particular the case of Bhakra Nangal Dam is addressed. Chapter 3 described the issues related with nuclear power and the costing exercise is conducted for a typical 235 MW CANDU reactor. Chapter 4 lists the environmental impacts of coal fired power stations and the costing undertaken for the Indraprastha power plant. Conclusions and recommendations are given in Chapter 5.

CHAPTER 2

Hydroelectric Plants - Environmental Aspects

2.1 Introduction

The total installed capacity of hydro electric power plants has increased from 559 MW in 1950 to 17215 MW in the year 1987-88. The hydro thermal mix has changed substantially since the early 1970s, in favour of thermal power plants. This trend is likely to continue in the future because of the growing awareness about the social and environmental disruptions associated with the development of large scale hydro.

Dams are constructed for a variety of functions - power generation, flood control, irrigation and water supply. Some side benefits include recreation and fish production. However, the creation of a reservoir not only creates social problems but also results in marked changes in the physico-chemical and biological characteristics of the impoundment and downstream areas. The diversity of effects in case of hydro electric projects makes it difficult to describe their environmental consequences within a quantified framework. Moreover, each such project represents a particular site that has a unique combination of features such as climate, soil and forest type, density of population, etc., therefore making generalisations extremely difficult.

The impacts of hydroelectric development can be classified into social and environmental. The most

prominent of these is the large scale displacement of people, an issue that has attracted much attention in recent years. Although current rehabilitation schemes offer good compensation, implementation, for a variety of reasons, leaves much to be desired. Even when land is given in compensation, several problems arise. First, is the lack of basic amenities and infrastructure in resettlement sites in which case settlers have to spend time and money re-establishing themselves. Second is the inferior quality of new land. Third is the problem of allocation of land already under occupation leading to conflict between the new and old settlers. Moreover, due to declining areas of vacant land suited to agriculture, problems of administration of resettlement schemes, and the scale of displacement under hydroelectric projects, compensation is in most cases given in cash for covering the losses of the oustees. However, with no standard technique for determining the value of land and other assets lost, the amounts given as compensation are arbitrary and in many cases inadequate. Further, a whole community is almost never rehabilitated in one place leading to the destruction of community life. For the tribals, especially, this has emotional costs that cannot be quantified.

Very often the land that is submerged under a reservoir is prime quality forest land. Forest is an extremely important segment of the ecosystem that not only provides forest products, but also serves other

functions such as providing a habitat for wild life, climate regulation and prevention of soil erosion. Moreover, it has great value to the tribal communities that live there. Forests meet their subsistence needs to a large extent and in many cases are also a source of income. Impounding of a large mass of water gives rise to water borne diseases around the dam area - like fluorisis, schistosomiasis and malaria. The impacts on human health include temporary and permanent disabilities, discomfort and in some cases, even death.

In the catchment area of reservoirs, uncontrolled cutting down of trees, continuous heavy pressure of grazing and faulty methods of cultivation increase the soil loss from the catchment. This keeps eroding the catchment and silting up the reservoir. The actual rates of siltation in most dams have been observed to be much higher than the rates assumed when the project was designed. Rapid siltation of the reservoir, if not taken care of, can lead to a decrease in the life of the dam, thus pushing up the cost of electricity generated.

Incorporation of these social and environmental costs in the cost of electricity generated is essential for arriving at its true cost. Describing each of these impacts, the following sections attempt to cost these, wherever possible. This is followed by a detailed case study of the Bhakra Nangal Project.

2.2 Impacts of Hydroelectric Power Plants

2.2.1 Social

<u>Displacement of People</u>

Displacement of people is one of the most important issues associated with large hydro electric projects. It has acquired great prominence today through widespread movements by several environmentalist groups all over the world. Some of the dams which have caused massive displacement are - Volta in Ghana (78,000 persons), Aswan in Egypt (120,000 persons) and Lake Kingi in Nigeria (42,000 persons).

An inevitable consequence of displacement of people is firstly, the 'loss of tangibles' like houses, private land, forest wasteland, public buildings and places of worship and secondly, the 'emotional and physical suffering' to the oustees during and after the process of displacement.

Compensation for assets

A valuation of tangible assets can be done on the basis of their market prices. However, most of these assets (for instance, land, shops, barns and wells etc.) are not traded in the market and consequently, the valuation of these in many cases is done arbitrarily with no standard technique followed. Compensation for land submerged by the Subarnarekha multipurpose project was based on indicators of quality of land yield and land tax. For purposes of reducing land tax, earlier on, many families

had registered high quality lands as low quality ones. They were therefore getting smaller amounts than they ought to for their lands (Areeparampil, 1987). In the case of the Hirakud dam, the compensation for Bhogra (Zamindari) land was decided by a village to village enquiry by revenue officers (Pattanaik and Mishra, 1987). These officials were influenced to raise the price of land with small bribes. The compensation for rayati land, on the other hand was calculated for each strip of land after taking into account the standard rent, soil type and village conditions, notwithstanding the fact that vast improvements were made on the land. As a result, the compensation was skewed in favour of the rich peasantry (Pattanaik and Mishra,1987). In the case of Tehri dam, the "value of the houses after deducting depreciation" was paid as compensation instead of providing an amount equivalent to the cost of reconstructing a dwelling place equal to the plinth area lost under submergence. The amount of compensation paid in several instances was also meagre and the price paid for land was not adequate for the purchase of equivalent amount of similar quality land elsewhere. For instance, the compensation given to Tehri oustees was highly undervalued for the simple reason that their houses of stone were considered inferior to brick houses. (More, 1990).

Not only is the compensation paid undervalued but also a large segment namely, landless labourers, artisans, tenant cultivators and people living on collection of

forest produce are left out. Also, the loss of remunerations from economic activities pursued in the past is not evaluated for compensation purposes.

Compensation for suffering to oustees

This includes the emotional and physical trauma that the oustees undergo during displacement. The causes of discontent are several. First, the oustees are almost never moved enblock but are scattered in far away places, thus making it impossible for them to re-establish their community ties. Very often, they are shifted to sites with a completely different physical environment. An example is the Pong dam oustees who were moved from Himachal Pradesh to the desert of Rajasthan which was, an altogether different habitat. This coupled with the absence of basic amenities forced them to return as landless migrant labourers. The oustees of the Rihand dam, particularly the tribals "have fallen into the typical cycle of increasing debt bondage, coupled with increasing destitution and intermittent employment as contract labourers in coal mines and elsewhere. Most were simply kicked out with nothing left to fend for themselves..." (Lokayan, 1987).

A measure of this discontent for obvious reasons of subjectivity is difficult to estimate. However, the rehabilitation policy based on the Land Acquisition Act, that recognizes that displacement causes great emotional and physical suffering to the oustees advocates an extra

15% of the total compensation to be paid for involuntary acquisition of land. This was not always adhered to. In the case of the Tehri Dam Project the authorities have paid this additional amount to only those oustees who protested by appealing to the court (Paranjpye, 1988). Moreover, there is no basis for the choice of this figure of 15% for measuring discontent. The degree of discontent might also vary significantly across people. For instance, for tribals who have very strong community ties and depend to a very great extent on the forest environment they live in, a shift to a completely new environment might lead to very high degrees of discontent. The Department of Environment and Forest `Guidelines' of 1984 quantify the suffering to oustees as 1.5 times the earnings in two years multiplied by the total number of displaced persons, a calculation that is debatable and arbitrary. First, the choice of 1.5 could very well be 2 or any other, and second, it does not cover 'non earners' (for example the forest dwellers or agricultural communities who might be depending on forest products/agricultural produce for meeting their subsistence needs).

Moreover, the levels of discontent get magnified when the displaced populations are very large. The Rehabilitation policy for the Narmada Valley Project is an example which attempts improvements over past policies in several ways. First, every family from whom more than a

quarter of its landholding is acquired will be provided irrigable land to the extent acquired from it. Second, a minimum of two hectares will be given to every family and every major son will be treated as a separate family. Third, apart from the resettlement grant and compensation in cash, a number of civic amenities including primary schools, dispensaries, drinking water wells and roads will be provided for the oustees. However, implementation of these can be difficult due to problems such as making available very large areas of land, providing alternative employment to people and other delays related to administrative inefficiencies. Non-implementation or even delays of rehabilitation schemes can severely affect the lives of a large number of people. In such cases, the viability of the project might be questioned. In cases of large scale displacement of people, therefore, an upper limit to the number of people that can be displaced must be defined right from the stage of design of the project. Beyond this cut off level a project should not be permitted at all. Within the limits defined by this level, a sensitivity of cost of power to displacement costs can be done. Assessing displacement costs simply on the basis of compensation paid would not be correct, because it only partially reflects the `discontent to oustees'. Compensation paid will only provide very minimum estimates of the cost of displacement. Perhaps, an upper bound can be based on the needs of the oustees. Eliciting information from the oustees regarding their

requirements about compensation and rehabilitation therefore becomes crucial.

Community Health

Diseases are introduced in the dam area due to water impoundment through several mechanisms. Water impounded behind the dam is more stable with less turbulence, is subject to less sunlight penetration and oxygenation. This increases the survival of disease organisms and the habitat for mosquitoes which are vectors of diseases such as malaria, encephalitis and yellow fever.

Malaria became highly endemic in the Raichur District of Karnataka after the damming of Tungabhadra.

The disease Schistosomiasis is caused by parasitic flatworms known as `schistosomes'. The larvae of these develop within the hedixes of freshwater snails. When people swim or wade in water contaminated by infected snails, the larvae enter the blood stream through the skin. The building of large- scale reservoirs increases the snails' habitat and conditions are created for much longer breeding periods. In Egypt, the building of the Aswan Low Dam caused the schistosomiasis rate amongst the population at some areas to rise from 21% to 75% (S. Maudgal, 1985).

Filariasis is caused by a parasitic worm which is transmitted by several species of mosquito that tend to breed in water-bodies rich in organic matter-marshes, sewers and badly maintained drains.

Flurosis, a bone deforming crippling disease was observed around Nagarjuna Sagar Dam in Andhra Pradesh. The mechanism by which the disease is caused is simple. Water seepage from the dam reservoir increases the ground water level. This water as it moves up dissolves fluorides, calcium and trace metals especially molybdenum. The molybdenum uptake by Sorghum plants - the staple food of poor people in the area increases. This Sorghum when ingested causes increased excretion of copper and copper deficiency along with increased intake of fluorides in drinking water is suspected to cause the disease.

Water projects also create conditions which favour the transmission of the disease, which may not be waterborne. For instance, bad sanitary conditions and poor quality of water are responsible for the transmission of dysentry, gastroenteritis, diarrhea, hepatitis and cholera.

The impacts of these diseases on human health discomfort, temporary or permanent disability and in some cases death is extremely difficult to cost. One technique for costing these impacts is the foregone earnings approach. Changes in environmental quality can have significant effects on human health. The monetary damages associated with health effects consist of foregone earnings through premature death, sickness and absenteeism and increased medical expenses. In the case of premature illness or death, social costs are incurred by partial or total loss of the individual's services to society.

The value of life or working time lost is normally equated with the value of an individual's labour which is the individuals' projected future earnings, discounted to the present. The loss due to absenteeism can be calculated based on the average daily earnings of the people concerned. The approach is highly data intensive which restricts its application. Moreover, it also does not provide the probability of occurrence of a disease. The approach implicity assigns a zero value on children, an unemployed or a physically handicapped person - an assumption that is questionable on both ethical as well as moral grounds.

2.2 Environmental

Loss of Forest

Building of the dam, formation of a reservoir and other construction activity in the vicinity of the area leads to submergence of large areas of land. Most of the time, very large areas of forest are lost. This is essentially a loss of the services or benefits the forest provides. These include the production of timber and other minor forest products and environmental services like prevention of soil erosion, climate regulation, production of oxygen, absorption of carbon-dioxide and provision of a habitat for birds and animals.

Placing a value on these losses is very difficult for several reasons. First, a natural forest is a balanced coexistence of trees, creepers, bushes, birds, insects,

water and soil, an inherent part of the life cycle on earth. The quantification of the significance of forests with respect to this life cycle is just not possible. Second, to tribals and other communities whose life is deeply woven around the forest, the value of this loss cannot be reflected by a monetary number. Third, the potential productivity (of timber and minor forest products) of a forest may be much higher than the actual. The use of actual productivity will, in such cases be an underestimation of the value of these benefits.

The standard practice in the past for costing this loss has been to cost only the loss of timber yields from a forest. Recently, some estimates have been made to cost the loss of some of the other environmental services too. T.M. Das (reported in J.B. Lal, 1990) uses surrogate market techniques to value the environmental benefits of a forest. This technique recognizes that many environmental services have no established market price but it is possible to estimate an implicit value for an environmental service (for instance, the production of oxygen) by means of price paid for a substitute (artificial production of oxygen) which is marketed. Das uses this technique to value the environmental benefits from a medium sized tree which yields a biomass of 50 tons over a period of 50 years. On the basis of this calculation, annual environmental services for one ton of biomass are worked out. The value of environmental

services for different forest types (Table 2.1) was then worked out using data on the organic productivity of each forest type. The environmental services that have been costed include production of oxygen, conversion to animal protein, soil conservation and maintenance of soil fertility, recycling of water and controlling humidity, controlling air pollution and providing shelter to birds and insects. Table 2.1 also gives the value of timber across different forest types. A comparison between the two shows environmental services (for the items covered) for most of the forest types having a much lower value than the value of timber. Since these do not include various important services such as bio-diversity, dependence of tribals on forests, it is doubtful that these estimates can provide even a lower bound on the cost of a forest. To value forest as a whole, several theoretical techniques exist that determine peoples' preferences and thereby place a value on the loss of a forest. Bidding games can bring out either a person's willingness to pay or willingness to accept compensation for the loss. However, most of the people affected directly by forest are tribals or people whose lives are centred around the forest, and very often they do not even come under the monetary gambit. Moreover, purchasing power of the people living in a forest is extremely low and may also differ widely. Further, judgement of the loss is subjective and again may across people. This technique has therefore a very limited application.

Perhaps, what can be done is a sensitivity analysis on the cost of electricity generated by first assigning the environmental services a value, say equal to that of timber, then a value, say twice that of timber, three times and so on. Obviously, the value of a forest would depend upon the state of criticality of a forest in the country. The more critical forests are felt, the higher is the premium on them. Since forest resources in this country are well below the Government of India's guidelines (33% of the land area to be under forest cover against barely 12% of effective forest cover that exists today), it is imperative that an upper limit be set on the loss of a forest. The sensitivity analysis can then be carried out within this limit.

Table 2.1: Value of a forest

Forest type	Env.services[1] (Rs. per hect.)	Timber[2]
Tropical Wet Evergreen	9,567	16,000
Tropical Semi Evergreen	9,567	18,000
Tropical Moist Deciduous	9,567	20,000
Littoral and Swamp	9,567	-
Tropical Dry Deciduous	9,567	-
Tropical Thorn	9,567	-
Tropical Dry Evergreen	9,567	-
Subtropical Broadleaved Hill	8,717	-
Subtropical Pine	8,717	7,500
Subtropical Dry Evergreen	8,717	-
Montane Wet Temperate	6,378	2,000
Himalayan Moist Temperate	6,378	8,000
Himalayan Dry Temperate	6,378	15,000

[1] Lal, 1990.
[2] ADB, 1992.

Siltation

Sedimentation of a reservoir occurs naturally whenever a river carrying sediment is obstructed by a dam. The origin of the sediment is the watershed. Uncontrolled deforestation, overgrazing, faulty agricultural practices in the watershed accelerate soil erosion resulting in increased sediment flows into the stream and finally into the reservoir. The rate of siltation of a reservoir depends on the rate of soil erosion which in turn depends on several factors - the important ones being the extent of deforestation, and the nature of soil particles. Where the catchment is forested the soil is protected from the effects of wind and water erosion. The soil erosion rates in such areas are naturally low. Difficulties in predicting accurately the soil erosion rates and therefore siltation leads to a discrepancy between observed and assumed rates (for which the dam has been designed) of siltation in the reservoir (Table 2.2). In cases of wide variations in observed and assumed rates of siltation, useful life span of the dam decreases considerably, thus increasing the cost of electricity generated.

Increased sediment deposits if not flushed or dredged out can reduce the storage capacity of the reservoir and therefore the life of a dam. The number of years required for the dead storage to be completely filled up with silt can be used for calculating the increase in the cost of electricity generated.

Table 2.2: Annual rates of siltation in selected reservoirs in India

Reservoir	Assumed rate (acre feet)	Observed rate (acre feet)
Bhakra	23,000	33,475
Maithon	684	5,980
Mavurakshi	538	2,000
Nizamsagar	530	8,725
Panchet	1,982	9,533
Ramganga	1,089	4,366
Thungabadhra	9,796	41,058
Ukai	7,448	21,758

Source: CSE, 1982.

Dam Failures

There are several causes of a dam failure. First, malfunctioning of equipment as in the case of the Machau II dam in India was responsible for 1500 deaths downstream in 1979. The reason was that the spillway gates could not be opened in time. Bad workmanship and design errors resulted in the failure of St. Francis dam in California which led to the death of 300 people (Goldsmith and Hildyard, 1984). The Malpasset dam near Frejus in Southern France failed causing the death of 421 people. The cause of failure was the unsuitable site on which the dam was constructed. The incidence of dam failures because of lack of an appropriate site might increase in the future.

Earthquakes and Dam Failures

The first case of reservoir induced seismicity was reported in the 1930s in California. This was the Lake

Mead Earthquake following which the dam on the Lake (Boulder Dam) was closed. The cause of seismic disturbances around the reservoir area is the pressure created by the large mass of water impounded behind a reservoir.

Most dams are designed to withstand earthquakes. The probability of occurrence of an earthquake over the lifetime of a dam, safety factors that need to be incorporated in the design of the dam to ensure stability in the event of a major earthquake are taken into account while designing a dam. However, the incidence of reservoir related earthquakes or seismicity has been on the increase. Table 2.3 throws some light on reservoir induced earthquakes and their magnitudes.

Table 2.3: Reservoir induced changes in seismicity

Dam Name	Location	Magnitude
Koyna	India	6.5
Kremasta	Greece	6.3
Hsinfengkiang	China	6.1
Oroville	U.S.A.	5.9
Kariba	Rhodesia	5.8
Hoover	U.S.A.	5.0
Marathon	Greece	5.0

Source: Goldsmith and Hildyard, 1984.

The impounding of certain reservoirs has been found to be responsible for triggering seismic phenomena irrespective of the seismicity of the region (Goldsmith and Hildyard, 1984). Examples are the Vouglaus Dam in

France, previously an aseismic zone where an earthquake occurred with a magnitude of 4.5, and the Koyna dam in Maharashtra. The Deccan Plateau region around the Koyna dam which is uniformly covered by Basaltic rocks is also an aseismic zone.

In the case of the Koyna dam disaster, a series of tremors were felt around the region while the reservoir was being filled in 1962. On 13th september, 1967, two shocks were felt, the first of which caused great damage to the village of Koynanagar, killing 177 people and injuring 2300 others.

The Tehri dam on river Bhagirathi is subject to immense controversy with regard to seismicity. The site's seismicity has been established at 9 points on the Richter scale, that is one point higher than was specified in the design. In the area, between 1971-73 an average of one or two earthquakes occurred in a year. There also appears to be heavy cracking in the rocks of the river gorge where the dam is to be built (Goldsmith and Hildyard, 1984). The implications of a dam failure would be disastrous keeping in view the fact that a densely populated area lies behind it. The hazards associated with hydroelectric power plants are generally ignored despite so much evidence on dam failures. The implications in terms of lives, property and assets lost are tremendous. Estimating the cost of property and houses submerged is difficult because they are not traded in the market. Moreover, techniques used for evaluating the current worth of these items requires a

lot of data which restricts their use. Also, the probability of a dam failure that needs to be accounted for in calculating the value of damages is difficult to determine. Nevertheless, even a qualitative presentation of the extent and nature of damages can be very useful for drawing similar comparisons with nuclear and coal based power plants.

Water Logging and Salinity

Increase in waterlogging and salinity is not associated with the dam as such but with the irrigation canals where proper drainage is lacking. Perennial irrigation in most cases raises the water table because of water seepage from irrigation channels. An increase in the water table dissolves the salts in the soil and water is drawn upwards through capillary action. Even before the water reaches the surface, it starts affecting crop yields by interfering with the capacity of plants to take up moisture and oxygen. When the saline water approaches the surface, it evaporates thus leaving behind salts that accumulate in the soil.

The costs of water logging and salinity can be estimated either by measuring the loss of crop productivity or the costs of improvements in the drainage facilities.

2.3 Bhakra Case Study

2.3.1 Introduction

The construction of the Bhakra Dam project was started right after independence. The 225.55 metres high Bhakra Dam is one of the highest straight gravity concrete dams in the world. Behind the dam, is a 96.56 kms long storage reservoir, called `Gobind Sagar' impounding 8 million acre feet of water, of which 6.3 million acre feet of live storage of water is available for irrigating 2.63 million hectares of land and improving irrigation in 1.42 million hectares in the states of Punjab, Haryana and Rajasthan (Bhakra Nangal Project, 1976). Large quantity of power is generated by power houses, one on the left bank and the other on the right bank with the total installed capacities of 540 MW and 660 MW respectively and two on the Nangal Hydel Channel at Kotla and Ganguwal with an installed capacity of 77 MW each.

The complete project comprises of the following eight units - (1) Bhakra dam and two Bhakra power plants; (2) Nangal Dam (3) Nangal Hydel Channel; (4) Two power houses on the Nangal Hydel channel at Ganguwal and Kotla; (5) Remodelling of a Roper headworks and Sirhind canal; (6) Bhakra Canal; (7) Bist Doab Canal and (8) Transmission line.

2.3.2 Cost of the Project

The design of the project, as visualised in the project report of 1953 can be divided broadly into three parts-

(a) the part concerned with the storage of water and its regulation; (b) the part responsible for distribution of water for irrigation and (c) for generation and transmission of hydro electric power. The storage of water and regulation were taken care of by the Bhakra Dam, the Nangal Dam and Nangal Hydel Canal. The distribution of water for irrigation was provided for through a network of canals. This network was largely built around the Bhakra Main Line which had three main branches. From the main branches were to take off smaller branches. In addition to these new canals built around the Bhakra Main Line, the project design also provided for (i) remodelling of the existing Sirhind Canal to enable it to carry a larger supply of water, (ii) remodelling of the headworks at Rupar, to make possible a larger discharge of water into the Sirhind canal, (iii) and the construction of a new Bist Doab Canal to cover an area which was facing shortage of water because of a sinking spring level.

For the generation of power, the project design of 1953 envisaged four power stations, two at the site of the Bhakra Dam and two on the Hydel Canal, with sixteen generating sets between them. The first stage of development, as visualised then was to cover only the two power houses on the Nangal Canal (with two generating sets in each) and the superstructure for two generating sets in one of the two proposed stations at the site of the Bhakra Dam (with only one generating set actually installed). The addition of two further generating sets in the power

houses at Nangal, the installation of five additional sets in the first power house constructed at Bhakra, and the construction of a second power house at Bhakra with four generating sets were to follow later as and when increased demand for power became evident.

A more detailed picture of the distribution of investment over the period upto 1961 (as visualised in 1953, and based on the projectdesign outlined above) can be seen from Table 2.4 (Raj, 1960).

Table 2.4: Distribution of Investment Upto 1961

	Rs. Crores
1. Investment on the storage and regulation of water for both irrigation and power	
1.1 Bhakra Dam	54.7
1.2 Nangal Dam	3.9
1.3 Nangal Hydel Canal	11.8
	70.4
2. Investment on the distribution of water for irrigation	
2.1 Bhakra Canals	36.5
2.2 Remodelling of the Rupar Headworks	1.3
2.3 Remodelling of the Sirhind Canal System	4.5
2.4 Bist Doab Canal	4.3
	46.6
3. Investment on the generation and transmission of power	
3.1 Superstructure for two generating sets and installation of one set	4.3
3.2 Power houses at Nangal with four generating sets	12.2
3.3 Transmission system	17.4
	33.9
Total Investment	**150.9**

The costing of electricity generated was done on the basis of the following:

- A 16 year construction period extending from 1948 to 1963.
- The time pattern of investment - 10%, 40% and 50% of cost in the first five years, following six years and the last five years respectively was assumed.
- Wholesale price indices were used to inflate the cost because a yearly break-up of total expenditure could be estimated but it was not possible to get this break-up for each input.
- The civil and electrical components form 60% and 40% respectively of the total cost.
- The additional investment after 1961, at 1953 prices was approximately Rs.19 crores.
- The assumed interest rate is 7%.
- The annuatised cost is worked out using a 12% discount rate.
- Life of the dam is 50 years.

The project provides benefits of both power generation as well as irrigation. The cost of electricity generated (based on the total costs including both the irrigation as well as the power component) is Rs. 0.72 per kWh. This cost would come down if one were to exclude the benefits and hence the costs towards irrigation. For this, a precise estimate of the increases in agricultural output on account of irrigation are required. However, the estimates available relate to the total output in the irrigated areas and not the net additions to output on account of irrigation (Table 2.A.2). Moreover, these estimates also include the costs of inputs like fertiliser, seeds, etc. Therefore, it is difficult to

arrive at the increases in production related solely to increases in irrigation.

An alternative is to look at the break-up of cost between the irrigation and the power components (Rs. 117 crores and Rs. 34 crores respectively as given in the project report). The cost of electricity generated (excluding the irrigation component of the costs) works out to Rs.0.184 per kWh (Table 2.5). The cost of electricity generated (based on the cost of dam and power generation component and excluding the cost of irrigation network) is Rs.0.37/kWh.

Table 2.5: Cost Estimates of the Bhakra Nangal Project (1990 Prices)

Capital Cost (cr. Rs.) attributed to irrigation	:	1159.00
Capital Cost (cr. Rs.) attributed to power	:	337.00
O&M Cost (cr. Rs.)	:	19.54
Interest during construction (cr. Rs.)	:	492.17
Annuatised cost (cr. Rs.)	:	119.00
Cost per kWh (Rs.) (based on the power component)	:	0.18
Cost per kWh (Rs.) (cost of dam and power generation system)	:	0.37

This estimate of cost (that includes the capital, operation and maintainance cost and interest during construction) is an underestimation of the cost of electricity generated because it does not include the social and environmental costs completely, that are

associated with the project. In the following sections, an attempt is made wherever possible to incorporate the costs of these impacts to the costs of elecricity generated.

2.3.3 Environmental and Social Impacts

Displacement

The Bhakra Nangal project involved the displacement of 5000 families. Of these 5000 families (36,000 people) displaced, land was acquired from about 2,180 families in the districts of Una and Bilaspur in Himachal Pradesh. They were promised to be rehabilitated in the districts of Sirsa and Hissar. To date only 730 families have been resettled. These families that were resettled were not given proprietary rights which continued to be vested with the state government. Moreover, in many cases, the land allotted to a family was even less than one tenth of an acre.

The land of Bhakra oustees was acquired from them at 1942-47 average prices, whereas allotments were made at 1952-57 prices. As a result, the oustees had to pay more for the lands alloted to them. Moreover, there was a steep rise in the price of land after 1947 because of influx of migrants.

Further, land to be given to oustees was acquired from landowners who fraudulently got the kind of land changed from `Banjar' to `Nehri' (good quality) in the revenue records and therefore the oustees had to pay much

more for the land acquired from them. ".....To illustrate, the land of village Ratta Tibba, district Hissar, was Banjar at the time of acquisition. Subsequently, the revenue records were tampered with and this land was shown as `Nehri...... (Lok Sabha Petition 1978-79).

Unsatisfactory compensation is reflected in the demands made by the oustees in the Lok Sabha Petition 1978-79. These include the following:

- Each family ousted from Bhakra Dam reservoir area may be allotted an economic and viable landholding of 10 acres.
- The land acquired from the oustees in the reservoir area may be evaluated on the basis of average price during 1952-57.
- Proprietary rights be given to the oustees.
- Enhanced sale proceeds paid to the landowner from whom land was acquired for allotment to the oustees may be borne by the Bhakra dam beneficiary states and the Central Government.
- The Bhakra dam oustees who have resettled in Haryana may be declared a backward class for a period of at least 10 years henceforward so that they may get special privileges for development.

Of these demands, the most important one is the demand for land. According to the figures available in the Union Agriculture Ministry, surplus land is available in the Bhakra dam beneficiary States.

Table 2.6: Surplus Land Available with the Beneficiary States

Name of State	Total area declared surplus	Area taken possession of by the Govt.	Area distributed	Area yet to be distributed
Haryana	20,973	14,525	9,313	5,212
Punjab	30,493	6,401	5,161	1,240
Rajasthan	2,45,844	2,20,517	1,21.662	98,855
H.P.	93,951	91,786	4,773	87,013
Total	3,91,261	3,33,229	1,40,909	1,92,320

Source: Kutlehria, Singh and Dogra, 1988.

If 10 acres are to be provided to each family (@ Rs.800/- per acre for cultivable land, from the 1953 project report of the Bhakra Nangal Project) the cost increases only marginally to Rs.0.187 per kWh. A doubling of the cost of rehabilitation increases the cost of electricity generated to Rs.0.191 per kWh. This calculation has been done after apportioning rehabilitation cost to the power and irrigation components of the project. Assuming, that the entire cost was borne by the power component, the increased cost of the electricity generated works out to Rs.0.20 per kWh and a doubling of the rehabilitation cost increases the cost of power to 0.22 per kWh.

Loss of Forest

The costing of the loss of forest in the Bhakra Nangal Project was oversimplistic and included only the loss of revenue from fruit and timber trees in the submergence area. A sensitivity of the cost of electricity generated

to changes in cost of forest loss by assigning forest a value equal to timber, twice and thrice as much as timber gives the following results.

Value of forest	Cost of power (Rs./kWh)
Value of environmental services (e) = value of timber (t)	0.196
e = 2t	0.208
e = 3t	0.221

Because of lack of data on the forest cover in the submergence area, we assumed that the entire uncultivated land (26,000 acres) is forested. The value of timber has been taken from Table 2.1. It is also assumed that the entire cost of forest is attributed to the power component of the project.

If apportioning of cost (of forest) is done between the power and the irrigation components then the cost of electricity increases marginally as shown below.

Value of forest	Cost of power (Rs./kWh)
Value of environmental services (e) = value of timber (t)	0.186
e = 2t	0.189
e = 3t	0.192

Siltation

While designing the Bhakra Nangal Project, suspended silt load of 35,053,725 tonnes per annum was assumed on the basis of actual silt observations in the past years. For

working out the volume occupied by silt deposits, an estimate of the probable density was made. The available data indicated a large amount of variation in the densities observed at various places and the upper and lower average values as 1.04 g/cm^3 and 1.44 g/cm^3 respectively were assumed for preliminary studies. Based on the observed silt data, the classification of silt assumed was coarse silt 33%, medium silt 57% and fine silt including clay 10%.

Total silt deposited in the Bhakra reservoir from 1959-87 works out to 934.9 million m^3 which is 9.47% of gross storage capacity. Silt deposited in dead storage is 505.11 million m^3 which is 20.77% of the dead storage capacity. The dead storage the dam was designed for was 2431.81 million m^3. From 1965-86 the average annual rate of siltation of the reservoir was 31.77 million m^3 as against the designed siltation rate of 23.31 m^3. Assuming the average future rate of siltation to be 40 million m^3 and since 20% of the dead storage level is already filled, useful life in the future is 48 years. The life of the dam with these assumptions still comes down to 65 years and therefore there is no increase in cost. Assuming that the dam has just five more years (taking the worst case) the cost of power generaration increases to only Rs.0.188 per kWh.

But more serious is the problem of the formation of a hump like structure in the reservoir because of very

high rates of siltation. The problem of siltation was more serious in the past few years because "Deposits of silt over the years have created a hump which acts as a silt barrier within the dead storage ... Since the reservoir is not to be depleted below the dead storage level i.e. 1462 ft. due to water and power requirements, there is little scope for breaking the existing hump with top elevation i.e. 1510 ft. and pushing it into the dead storage zone near the dam... It will be worthwhile to consider depleting the reservoir to some extent even below the dead storage, for at least two consecutive years, so as to break down the hump and also to help in moving the same towards the dam thereby increasing the possibility of bringing the silt under the influence of density currents that may be set up. However, this proposal has to be weighed against the loss in power generation......" (Bhalla and Rajpal, 1989).

Seismicity

No cases of seismicity have been reported in the dam area. Moreover, this factor is taken care of in the design of the project.

Diseases

There have been no cases of reservoir induced diseases.

2.3.4 Results

The cost of electricity generated without incorporating costs of social and environmental impacts is Rs.0.18/kWh

(based on the cost of the power component) and Rs.0.37/kWh (on the basis of the cost of the dam and power generation system and excluding the cost of the irrigation network). A sensitivity analysis of the cost of electricity generated to displacement costs, the loss of a forest and siltation impacts shows only a small increase in the cost of electricity generated. Compensating the oustees by giving them land would increase the cost of power to Rs.0.20/kWh (with the entire cost attributed to power generation) and a doubling of cost increases the cost of power to 0.22/kWh. Similarly, incorporating the loss of a forest by say, assigning it a value twice as much as timber, the cost of power increases to Rs.0.21/kWh. If one were to double the cost of environmental services as well as displacement the cost of electricity generated increases to Rs.0.24/kWh. It is important to mention that this sensitivity analysis is carried out only with a range defined by the upper limits that are to be set for both the loss of a forest as well as the number of people displaced. Beyond these limits the project is not considered viable.

APPENDIX 2.A

Irrigation Aspects of the Bhakra Nangal Project

A gross area of 6.6 million acres was to be commanded by the project, 4.2 million acres on a perennial basis and 2.4 million acres on a non-perennial basis. Of the commanded area of 6.6 million acres, the actual area that was proposed to be irrigated per annum was 3.6 million acres. Punjab accounted for 2.2 million acres, Patiala and East Punjab States Union (Pepsu) for 0.8 million acres, and Rajasthan for 0.6 million acres. Detailed and thorough studies have been made of the likely effect of the project on the pattern and volume of agricultural production. The Crop Planning Committee was appointed by the Government of Punjab in 1954 to forecast the impact of irrigation on the agricultural output in the command area. The impact of irrigation on agriculture in a region depends on a variety of factors. These are partly of a technical and partly of an institutional character. The amount of water made available by irrigation, the soil conditions in the region, and the pattern of rainfall. The elaborate area covered by the Bhakra Nangal project can be divided broadly into three regions, according to the source and extent of the water now available for cultivation and the nature of irrigation that is proposed to be made available by the project. The first region, immediately south of Rupar, receives good rainfall during the monsoons, and the spring level is only about 30-60

feet below the ground. However, only restricted perennial irrigation was proposed for this area which means that it would not be supplied with water during the monsoon months. The second region, covering areas on both sides of the Sutlej, west of Rupar, was already receiving non-perennial irrigation through inundation canals, and had again a high spring level. But the present inundation canals would be cut off as a result of the construction of the Bhakra Dam, and the proposal was, therefore, primarily to provide an alternative source of perennial supplies. The third region, consisting of the arid areas of the Hissar and Rohtak districts and the tracts on the borders of Rajasthan, receives very scanty and undependable rainfall. It was, therefore, to receive unrestricted perennial irrigation. These regions cut across the boundaries of the three States covered by the project. Table 2.A.1 gives statewise distribution of irrigation provided by the project. The estimated total output following irrigation as calculated by the Crop Planning Committee is given in Table 2.A.2.

Table 2.A.1: Statewise distribution of irrigation provided by the project (in lakh acres)

States	Culturable commanded area	Annual Irrigation: Restricted perennial	Non perennial	Perennial
Punjab	38.54	4.94	1.72	15.44
Patiala and Punjab States Union	10.88	2.21	0.38	5.63
Rajasthan	9.20	-	-	5.70

Source: Raj, 1960.

Table 2.A.2: Annual Irrigation Benefits of the Bhakra Nangal Project

Crops	Prodn. (000 tons)	Area (000 acres)	Price (1990) Rs/tonne	Rs/acre	Total value of output (Rs. crores)
Fodder	6028.2		400		241.1
Sugarcane	148.2		370		5.5
Cotton	79.4		22020		174.8
Rice	31.4		3458		10.9
Groundnuts	36.3		5970		21.7
Other food-grains	163.4		1900		31.0
Vegetables		35.7		10350	37.0
Wheat	656.1		2170		142.4
Total					664.4

Source: Crop Planning Committee, 1954.

Salinity and Water Logging

In Punjab and Haryana, the states benefitting most from the Bhakra Nangal complex, the problem of water logging and salinity is very serious. A 1986 study of Hissar District indicates that improved water management has still to make headway. As such there are considerable water losses in the irrigation system resulting in substantial ground water recharge. Also, as a result of continuous addition to the ground water reservoir, the water table has been rising at a rate of more than 50 cm/yr. Ground water simulation studies have shown that nearly 50 per cent of the area is likely to become water logged and saline by 2000 A.D. if adequate water management measures are not enforced.

The average rise in the water table in the six year period 1955-61 in the Bhakra Canal areas has varied from 5 ft. to 12 ft. as against 1.7 ft. to 3.0 ft. for a

six year period before 1955. For the fifteen year period before 1955, the rise was 2 ft. to 8 ft. Moreover, since 1955, the rise of the water table has been continuous.

A study undertaken in the Ferozepur - Faridkot - Bhatinda area reports, "In northern part of the tract, the water table has gone high (less than 5m below natural surface) which was once intensely deep. About 5,500 k.m. area has fallen in the grip of water logging. The water is generally potable to marginally brackish" (S. Banerji and S. Ghotge).

Areas having depth to watertable less than 5m; it includes Faridkot, Muktsar, Kottapura, Budhlada, Jhuniar, upper reaches of eastern canal and areas adjacent to the Sutlej river.

The watertable in these areas has been rising regularly due to sub-soil flow from high watertable areas, rainfall, recharge of ground water due to charge of Sutlej river, seepage losses from canal system and percolation from canal irrigated fields.

As the total recharge always exceeded the withdrawal of groundwater, the watertable rose further beyond economical and suitable levels and parts of these areas fell in the grip of waterlogging. Crops, land, urban property and ecology of the tract has been badly affected. The crop yield (except rice) has gone down. Cotton is being eliminated rapidly. Impacts of water logging can be measured in terms of decreases in crop output. For instance, as mentioned above, cotton was

eliminated, implying a loss of 79,400.5 tonnes of cotton annually. Overall, "the watertable in this zone had been rising regularly with average rate of 0.2m to 0.4m annually. The rate of rise has increased during the last decade and these have been worked out to be 0.85m, 1.10m, 1.40m, 0.61m and 0.60m per year of Bhatinda, Kotbhai, Abohar, Lambi, Sangat and Talwandi areas respectively,... the rise has been mainly due to the sub-soil flow from high watertable areas and irrigation and seepage from canal systems. The recharge due to rainfall is small. The depth-to-water in these areas in June, 1983 was approximately 12.5m, 11.3m, 11m, 15.6m, 15.2m and 17m respectively (in the same order as above). It is, therefore, easy to see that if these rates of rise continue to occur, the watertable would take about 9.6, 12,8,17 and 20 years to rise to a depth of 5m in the respective areas.

The most arid area has 20 years before the water reaches 5m. For Punjab as a whole, "due to the construction of big canal systems, the watertable started rising due to seepage from the unlined channels. It was estimated that losses upto 17% from mainland branch canals, 8 per cent from distributaries and 21 per cent from water courses were taking place. This resulted in severe water logging and increase in salinity and alkalinity problems in the command areas.

CHAPTER 3

Nuclear Power Generation - Environmental Aspects

3.1 Introduction

In 1990-91 nuclear power accounted for 11.7% of the total installed capacity and 16.8% of the generation worldwide.

The oil shock of 1973-74 was the prime-mover in the promotion of nuclear power as a cheap and safe alternative to the depleting resources of fossil fuels. This was given further impetus by the second oil shock in 1979, but could not be maintained during the cheap oil era of 1985. Thereafter, the basic justification for hailing nuclear power was the fuel diversity it afforded. However, the nuclear industry world wide is suffering a crisis in the face of mounting capital costs and poor plant performance. Moreover, there is growing distrust regarding the safety aspects of this technology, largely in response to the Chernobyl accident in 1986.

Nuclear power generation accounts for less than 2.5% of total power generated in India. In 1990/91, 6244 GWh of electricity was produced by nuclear energy sources. The Indian reactors are of the CANDU type. At present there are seven units in operation with a total capacity of 1465 MW. Seven more units of 235 MW each are under construction at Narora, Kakrapara, Kaiga and Rawatbhata. The Department of Atomic Energy plans to install 10,000 MW of nuclear capacity by the turn of the century. This targeted capacity may not be achievable in light of the various technical and financial constraints.

The hazards from releases of a nuclear plant are distinctly different from the releases from other sources (thermal plants) in that they are radioactive. The design of nuclear power plant, however, is such that during, normal operation the releases of radioactivity are negligible. But in the event of an accident the consequences are not only limited to the regions in the vicinity of the plant but are also far-reaching both in spatial and in the inter-generational context.

The two key concerns in the sector are regarding long term waste management and the eventual decommissioning of plants.

Wastes generated from a nuclear plant may be classified into three types - low, medium and high level - depending on the level of radioactivity . The low active wastes comprise mainly trash, mops, glassware, which are either incinerated or baled into small tablets and then stored in leak-proof trenches. Medium level wastes such as process residues and some highly contaminated articles are also stored in reinforced cement concrete vaults which are sealed for any leakages. Internally steel lined and externally water-proofed pits called "tile-holes" are used for burying other wastes. The problem associated with wastes is that of long term disposal of high level wastes. In addition, disposal of the reactor components at the end of the economic life of a plant also poses problems. This issue is inextricably linked to the concerns about decommissioning. High level

wastes like spent fuel and the by products of fuel reprocessing have to be removed before decommissioning. The spent fuel is highly radioactive and remains more so than the uranium ore for about 3 million years. It requires remote handling. Although the spent fuel can be reprocessed, slowdown in the worldwide nuclear agenda, tardiness of the breeder programme and concerns about nuclear proliferation have undercut the rationale for reprocessing. The search for sites for disposal of high level wastes has also become a contentious issue.

According to the Nuclear Energy Agency about 160,000 metric tons of spent fuel will accumulate in the OECD countries by the year 2000 and to quote Cynthia Pollock, (Pollock, 1986) "Existing utility holding ponds are not large enough to accommodate this increase, nascent away-from reactor storage techniques are unlikely to be sufficiently developed and permanent repositories will probably be stalled by political and technical obstacles". The only alternative to a lack of burial site for spent fuel, is mothballing of the reactor unit and deferring the decision to bury wastes.

Dismantlement of a retired unit also generates wastes and the contaminated and activated components of a reactor have to be disposed carefully. Decommissioning activities, apparently may be hindered by the lack of both high and low level disposal facilities.

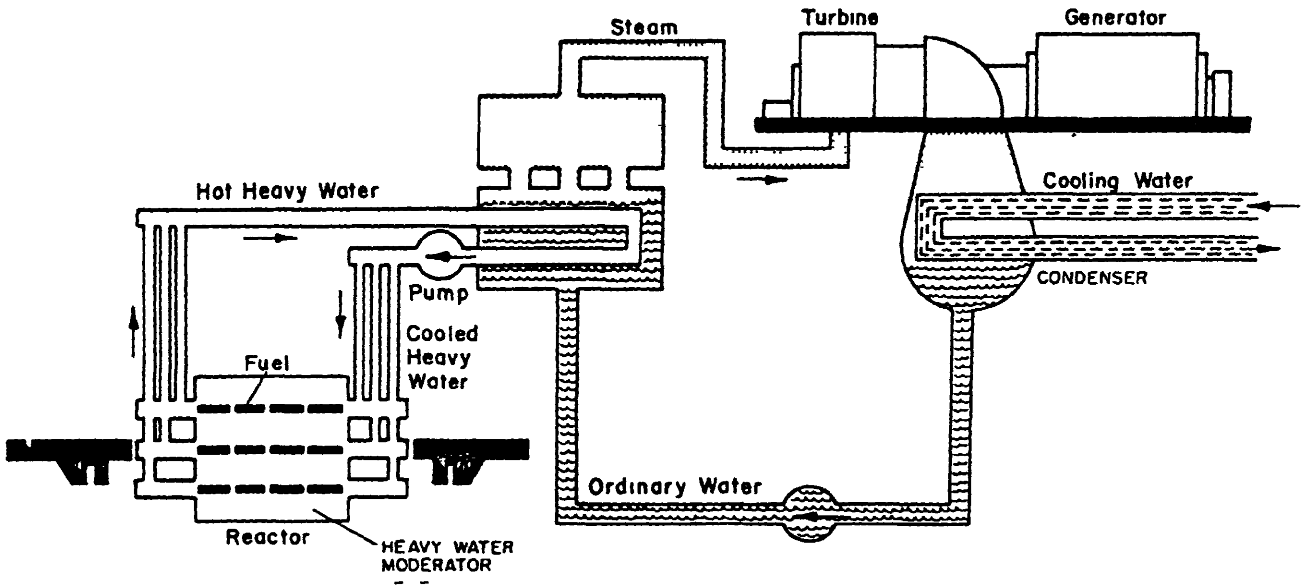
The other uncertainty regarding decommissioning

relates to its costs. Uptil now cost estimates have been based on (i) scaling up costs of decommissioning small research facilities, (ii) from calculations based on fixed percentage of construction costs and (iii) from site-specific engineering studies. Not only do the estimates of costs vary due to differences in methodologies adopted for estimating them but they are also dependent on the size, type and number of reactors and the procedure for decommissioning. This variation, however, can largely be attributed to lack of decommissioning experience worldwide.

This chapter gives a brief description of the CANDU reactor, radioactivity associated with the operation of nuclear power plants, impacts of radioactivity under normal operating conditions and the accident scenario. The issues of waste management and decommissioning of plants are also discussed. Finally, the economics of nuclear power generation is examined.

3.2 The Reactor

The Indian nuclear reactors are mostly of the CANDU type. These are pressurized heavy water reactors (PHWR), which are natural-uranium fueled, heavy water cooled and moderated. In the PHWR there are two separate circulating water systems as shown in Figure 3.1. The water that circulates through the reactor core is under high pressure and temperature ($600^{\circ}F$). This is then circulated through a heat exchanger immersed in the water of a second



Source: Adapted from Ontario Hydro, SI Education Program, 1977

Figure 3.1: The CANDU-PHWR System

circulating system. This water, which is at a much lower pressure gets converted to steam which turns the steam turbine that drives the generator. There is a third circulating system (cooling system) to condense steam back to water, which is similar to that in the coal plants.

In a PHWR it is easier to contain the radioactive materials that inevitably leak through the fuel rod cladding as the first pressurized system is completely closed. As the fuel is used up in a reactor and neutron-absorbing impurities accumulate, the reactivity of the core decreases. To compensate for this in a more uniform manner than is possible with control rods, some boron is added to the cooling water at the beginning of the reactor's operating period. As the overall power level gradually lessens, the boron, which has been absorbing neutrons, is gradually removed from the coolant allowing more neutrons to take part in the reaction. The reaction between boron and neutron produces lithium and tritium (a radioactive form of hydrogen).

In the following sections a brief description of radioactivity and environmental pathways of the same is given.

3.3 Radioactivity

Environmental considerations around nuclear plants are concerned mainly with the deleterious effects of radioactive effluents.

Any attempt to understand and therefore model the health related effects due to radiation requires a familiarity with the nature of radioactivity. A brief description is given below.

Six main types of radiation are produced as the excited nuclei formed in a nuclear reactor decay :

(i) Alpha particles, comprising the nuclei of helium atoms.

(ii) Beta particles, which are essentially electrons.

(iii) Gamma radiation i.e. electromagnetic radiation.

(iv) Fission fragments which are nuclei of atoms produced when the original nucleus is sufficiently unstable to rupture into two lighter nuclei.

(v) Neutrons which accompany fission.

(vi) Protons emitted directly from a nucleus as produced by recoil when a neutron is scattered by a hydrogen atom.

All these radiations can cause ionizations and each type has a different capacity to damage human health.

Energy of the order of 10-30 ev has the capacity to break a chemical bond, ionize an atom or alter the chemistry of cells leading to biological damage. The alpha, beta, gamma and neutron radiations from radioactive nuclei typically have energies in the Mev range. Hence, they can potentially damage hundreds of thousands of cells. The damage produced depends on the physics of interaction which is dependent on the type and energy of the particle involved.

In particular, the effects of these ionizing radiations on cells are modified by :

(i) Amount of radiation energy absorbed by the cells (which is measured in Grays).

(ii) Quality of the radiation.

The quality of different types of radiation are compared on the basis of the average energy released per unit length along the track they follow through the irradiated medium.

This is termed as the linear energy transfer (LET) of the radiation.

LET is dependent on mass (M), energy (E) and the charge (Z) of the ionizing radiation.

Energy lost in a material of thickness X is $E \propto \frac{Z^2 M}{X}$

When LET values are high, then there are numerous ionizations in the affected area and the probability of harmful biological effects (even at relatively lower doses) is high.

An alpha particle being about 2000 times as massive and having twice the charge of an electron loses energy at a much greater rate. For instance it only takes 0.0076 cm of silicon to stop a 10 MeV alpha particle while it takes 2.2 cm of silicon to stop a beta particle with the same energy. Therefore, an alpha particle can produce much more local damage than a beta particle with the same energy.

A neutron has no charge and hence is difficult to stop. It loses energy by collisions with nuclei and thereby causes considerable harm. Since a neutron does

not lose energy continuously as charged particles, the concept of thickness required to stop it is irrelevant. What is important is the thickness required to reduce the intensity of the neutron source. Concrete is often the material used to attentuate neutrons. A gamma ray also does not have any charge (in addition, it does not have any mass). Hence in this case too it is important to talk of a thickness to reduce the intensity of the rays.

Alpha particles cannot penetrate beyond the first layer of the skin. Beta particles are stopped by 1-2 cm of human flesh, depending on the particles energy and gamma radiations are highly penetrative.

3.3.1 Radiation Units

In the context of radioactivity, it is important to understand what the various units of measurement stand for. The unit of radioactivity, is Becquerel, and is defined as the number of nuclei which break up each second in a particular sample.

1 Becquerel = 1 disintegration/second

It is more meaningful to measure radiation in terms of energy deposition and the unit for this is Gray, where

1 Gray = 1 Joule/kg

To convert dose to dose-equivalent taking into account the relative biological effectiveness of radiation in causing malignancies, a quality factor (Q) is used. The unit for dose equivalent is Sievert.

1 Sievert = 1 Gray x Q

Q = 1 for electrons and electromagnetic radiations

Q = 10 for fission neutrons and protons

Q = 20 for alpha particles and fission fragments.

Becquerel, Gray and Sieverts are the SI units of measurement. The conversion to the older system (curies, rads and rem) is as follows :

1 Curie = 37 Giga Becquerel

100 rad = 1 Gray 1 rad = 0.01 Joules/kg

100 rem = 1 Sievert 1 rem = 1 rad x Q

3.3.2 Environmental pathways of radiation

The earth has a naturally radioactive environment and mankind has evolved in this environment. Man is exposed to external radiation consisting of cosmic radiation and radiation from the decay of naturally occurring radionuclides (3H, 14C, 22Na, 40K, 87Rb). The two families of radioactive elements originating with 238U and 232Th account for much of the radioactivity man is exposed to. The contribution of natural background radiation is 2 milli Sieverts per year (Krishnan et.al., 1988).

Cosmic rays are high energy radiations which enter the earth's atmosphere and interact with nuclei of atoms present to produce neutrons, protons and radionuclides such as 3H, 7Ba, 14C, 22Na and 24Na.

Terrestrial sources of radiation are those which have been in the earth's crust for billions of years and which have not decayed substantially since then. These include 40K and 87Rb and 238U and 232Th. The half lives* of each of these is of the order of billion years. These primordial radionuclides present in air, water, soil, rocks and food material result in both external and internal radiation doses. As mentioned earlier, the greatest contribution to human exposure from natural sources comes from 238U and 232Th. All rocks and soils contain trace quantities of uranium and thorium and their decay products. In the uranium series the highest contribution is from radon and its short-lived decay products. In the nuclear power plants, as the uranium undergoes fission, each of the fissioned atoms is replaced by two fission products and several neutrons. Since the fission product nuclides have an excess of neutrons as compared to the number required for nuclide stability, the fission products undergo successive decays till they reach a stable state. It is during this process that radioactive effluents are generated. Table 1 enumerates a few of the important radioisotopes produced in nuclear reactors. This radiation can reach human beings via various modes, and at various stages of operation of a nuclear power plant (mining, fabrication, nuclear

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* A "Half-life" is the time required for half of the radioactive atoms to decay and it differs for each type of radioactive atom.

reactor- storage/reprocessing). The radioactive material may be discharged either in gaseous, liquid or solid forms.

Table 3.1. Important radioisotopes produced in nuclear reactors

Isotopes	Half-Life	Mode of decay
Tritium	12.3 y	B^-
Cobalt - 60	5.27y	B^-
Strontium - 90	28.8 y	B^-
Ruthenium - 106	366 d	B^-
Iodine - 131	8.04d	B^-
Caesium - 137	30.2 y	B^-
Plutonium - 239	24000 y	α
Americium - 24	432 y	α

Source: Saunders P.A.H., B.O. Wade, "Radiation and its Control", Nuclear Power Technology, vol.3: Nuclear Radiation, W. Marshall, ed., Clarendon Press, Oxford, 1983.

If it is discharged into the air, exposure can occur via

(i) direct inhalation or

(ii) external irradiation from a radioactive cloud.

(iii) contamination of plants/animals and subsequent ingestion by human beings.

The significant radioactive airborne effluents consist mainly of noble gases (zenon and krypton), tritium and radio-iodines. These are of environmental concern because of their long half lives. Other radioactive gases that are shortlived are released after various forms of treatment such as filtration and delay systems which allows the shortlived radioactivity to decay.

Radioactive liquid effluents are produced by leakages from the reactor boundary and also due to various

discharges, for instance, from laboratories, laundry, showers etc. These are normally treated by a liquid radioactive waste treatment system and discharged with the cooling water. The significant radionuclides include radio-iodines, tritium and caesium isotopes.

Most of the radio-activity is contained in the spent fuel which is sent for reprocessing and therefore does not constitute solid waste at the plant. Filters and resin columns used to remove radioactivity from liquid and gaseous effluent streams, constitute solid wastes with a fairly high concentration of radionuclides. A less significant source of solid radioactive waste is contaminated material such as gloves, laboratory ware, etc. which are used in operations involving radioactive substances. Various methods are in use for disposing these including incineration. Radionuclides released in airborne or liquid effluents during reactor operation undergo a series of complex physical, chemical and biological processes before reaching man. Such processes depend upon the location of the reactor, meteorological conditions and the different exposure pathways. The noble gases released from the reactors usually make the largest contribution to the dose received by the local population. Once released, these gases tend to remain in the air with negligible deposition on the ground. Also they do not dissolve much in water. The only significant route of exposure of man is by external irradiation from the cloud of radioactive gas, which may pass overhead or may envelop

him if he is immediately beneath the release point. The dose rate falls off rapidly with distance from the release point and the most significant individual exposures occur within a few kilometres. However, appreciable collective doses can occur at larger distances, if the released material passes over large towns.

Most of the noble gases emit both beta and gamma rays. The former cause primarily irradiation of the skin, whereas gamma rays cause fairly uniform irradiation of all of the body tissues. Apart from 85 Kr, the other fission noble gases have half lives of less than a few days and consequently they decay before there is any significant build up. However, 85 Kr rapidly disperses in the atmosphere and because of its long half life accumulates and results in small doses to the world population. Tritium present in airborne effluents from reactors can irradiate the local population primarily through direct inhalation and secondarily through ingestion. Although the physical half life of tritium is around 12 years, the biological half-life when taken into the body is around 10 days and is rapidly excreted in urine. As it also emits beta rays of very low energy, its toxicity is low. Also during inhalation, only a very small fraction of the inhaled material is retained in the lung and therefore its intake is fairly innocuous. The dose rate declines very gradually for the first 100 km from the release point, with a sharp decrease thereafter.

Radioiodines of concern are ^{131}I and ^{129}I. Doses from ^{81}I are difficult to determine since iodine may take particulate, elemental, organic or hypoidous acid forms. Elemental iodine readily deposits on foliage and enters the cow-milk-man pathway. Particulate iodine have less deposition rates on vegetation, followed even less by elemental iodine. The behaviour of hypoidous acid is uncertain and may simply decompose to the elemental or organic forms. The three major pathways leading to irradiation are a) inhalation, b) grass-cow-milk, c) via foliar contamination of vegetables. The pathway involving milk is generally the one leading to the biggest value of dose per unit released. The radioiodines are of relatively high toxicity since after inhalation or ingestion they accumulate in the thyroid. Other airborne effluents include carbon-14, particulates etc. Carbon-14 makes a very small contribution to the local collective dose. Doses from particulates vary, but are in any case quite low. Significant particulates are Co-60, Cs-134, Cs-137 and Sr-90.

Radionuclides discharged in liquid effluents may result in doses to man through drinking water and fish consumption. Also where water for irrigation is contaminated with radionuclides, deposition on crops can be significant especially with the adoption of sprinkling methods. Liquid effluents other than tritium include Cs-137, Cs-134, Co-60, Mn-54, Ce-144, Cn-51, Sb-125 and Ru-106.

Table 3.2. Important pathways for particular groups of nuclides

Type of radio-nuclide	Examples	Radiotoxicity class*	Important pathways+	Type of exposure	Part of body irritated
Noble gases	^{133}Xe	4	Directly from airborne material	External irradiation	Whole body
Iodines	^{131}I	2	Directly from airborne material	Inhalation	
			Air-ground-cow Air-ground-vegetables	Ingestion	Thyroid
Tritium	^{3}H	4	Directly from airborne material	Inhalation & direct absorption via skin;	Whole body
			also via water	ingestion	
Other fission	^{106}Ru	2	Various including discharge to sea, contamination of seaweed, and hence of foodstuffs	Ingestion	GI tract (^{106}Ru)
	^{90}Sr	2	Various, including discharge to rivers or sea, contimination of fish	Ingestion	Bone (^{90}Sr)
	^{137}Cs			Ingestion	Whole body (^{137}Cs)
Metallic activation products	^{60}Co	2	Discharge into ground, rivers, sea; then to fish	Ingestion	GI tract or Whole body
	^{65}Zn	3			
Trans-uranic elements	^{239}Pu ^{241}Am ^{242}Cm	1	Various including discharge to sea, then incorporation into foodstuffs	Ingestion	Bone, liver
	^{237}Np		Resuspension of contaminated sediment	Inhalation	Lung
Carbon	^{14}C	3	Various	Inhalation, Ingestion	Whole body

* radioactivity class: 1. high, 2. medium, 3. medium low, 4. low
\+ in order to avoid undue complexity in the table, only the most important routes of exposure have been included.

Source: Johns T.F.,'Environmental Pathways of Radioactivity to Man', Nuclear Power Technology, vol.3: Nuclear Radiation, W. Marshall, ed., Clarendon Press, Oxford, 1983.

Solid wastes could contaminate local water supplies indirectly by seepage or by leaching. However, generally the speed at which the contaminated liquid percolates is very slow, because of various processes such as absorption, ion exchange mechanism precipitation, colloid filtration etc. Consequently, a large fraction of the radioactive material would decay.

3.4 Impacts from radiation emanating from nuclear power plants

3.4.1 Under normal operating conditions

High level of radiation doses may be extremely harmful to the population exposed to it. The extent of damage is dependent on a number of factors such as the age distribution of the population and the type of radiation.

To recapitulate most of the noble gases have half-lives of less than a few days (with the exception of 85Kr) and hence after they are released from an operating reactor, they decay before there has been any significant build-up globally. The released 85Kr becomes widely dispersed in the atmosphere, where it remains for long (given a half life of 10 years), and emits beta rays. This leads to a small amount of exposure of the skin of people living near the release point. Tritium may be released in the gaseous or liquid form - in the form of tritium gas/tritiated water vapour or as tritiated water. The physical half-life of tritium is long (about 12 years), but the biological life is short (only 10 days) as it is rapidly excreted in the urine. Because of this

rapid excretion, radiotoxicity of tritium is low. In sharp contrast are the radioiodines, which accumulate in the thyroid and are highly toxic. As they are also volatile, isotopes of iodine are likely to be released from faulty fuel elements in operating reactors.

It is claimed that radiation hazards from the nuclear industry is one of the most controlled risks. The nuclear plants are designed in a near fault-proof manner to minimize the risks of any radiation leaks. In other words safety is built into the design of the nuclear plants. Moreover, the PHWR systems are alleged to have intrinsic advantages with respect to safety both during normal operations and accident conditions.

According to the Department of Atomic Energy's (DAE) document on the safety of the Indian PHWRs (DAE, 1986), the components and structures that affect the safety of a reactor are subject to stringent performance and reliability standards. The quality requirements for design, fabrication, construction and inspection for these systems is of the highest order. The safety related equipment inside the containment building is designed to work under high stress conditions of an elevated pressure and temperature resulting from the loss of coolant accident. It is also ensured that the process and safety systems are separated clearly - both physically and functionally. There is adequate redundancy in the systems to ensure that the minimum safety functions operate even in the event of failure of single active components in the

system. In addition, the key safety features characterizing a PHWR are availability of natural uranium dioxide as fuel, use of heavy water as coolant and moderator and pressure tube. Natural uranium dioxide has a low content of fissile material and thus precludes the possibility of a reactivity accident during fuel handling or storage. Moreover, reactivity in the core may not increase tremendously in the event of a mishap causing redistribution of the fuel.

Thermal characteristics of UO2 viz. low thermal conductivity and high specific heat also afford an advantage in that all heat generated in a fast power transient is absorbed by the fuel. The other advantages of using UO2 as a fuel include the binding of fission products in the UO2 matrix which are released only at temperatures much higher than the temperatures during normal operations. Moreover, as UO2 is chemically inert to the coolant water, the radioactive releases from a defective fuel are limited. With the "on-load" fuelling facility, defective fuel can be replaced at any time.

The neutron generation time for a natural uranium fueled reactor is greater than that for reactors fueled by enriched uranium. Hence, for a given reactivity, neutron transients are slower, making the reactor easier to control. Use of heavy water as a modertator provides large gaps between the fuel channels. The moderator occupies these gaps and the control devices are placed in

this low pressure and low temperature moderator environment, which precludes fast ejection of these control devices.

In addition to the above features, there are many other design specs which ensure the safety of a PHWR. Besides the design specs, other measures like suitability of a site to locate these plants, taking into account the geological and seismic considerations and the likelihood of extreme meteorological phenomena, such as flooding, cyclones is also studied intensively.

Although, the design of the plants ensures that the likelihood of malfunctions leading to accidents is small, precautions are still taken to preclude such events. The safety systems provided in PHWR, include the reactor shutdown systems, emergency core cooling systems and the containment system. Accident analysis is also undertaken for the reactors to set the performance standards for the safety systems and also to demonstrate the minimal risks from the reactor system. This analysis involves hypothesing about events that may initiate an accident, further identifying the consequent event sequences and evaluating the sequence in terms of radioactivity releases and the resultant doses to the public. Another integral part of this analysis is assignment of reliability targets to all the safety related systems. Hence, the deterministic approach to safety is supplemented by a probabilistic one in as much as reliability targets for individual systems are accounted for.

Moreover, each site is equipped with an Environmental Survey Micrometeriological laboratory which is responsible for monitoring radiation levels both during the pre-operational stage and the operational stage of a plant.

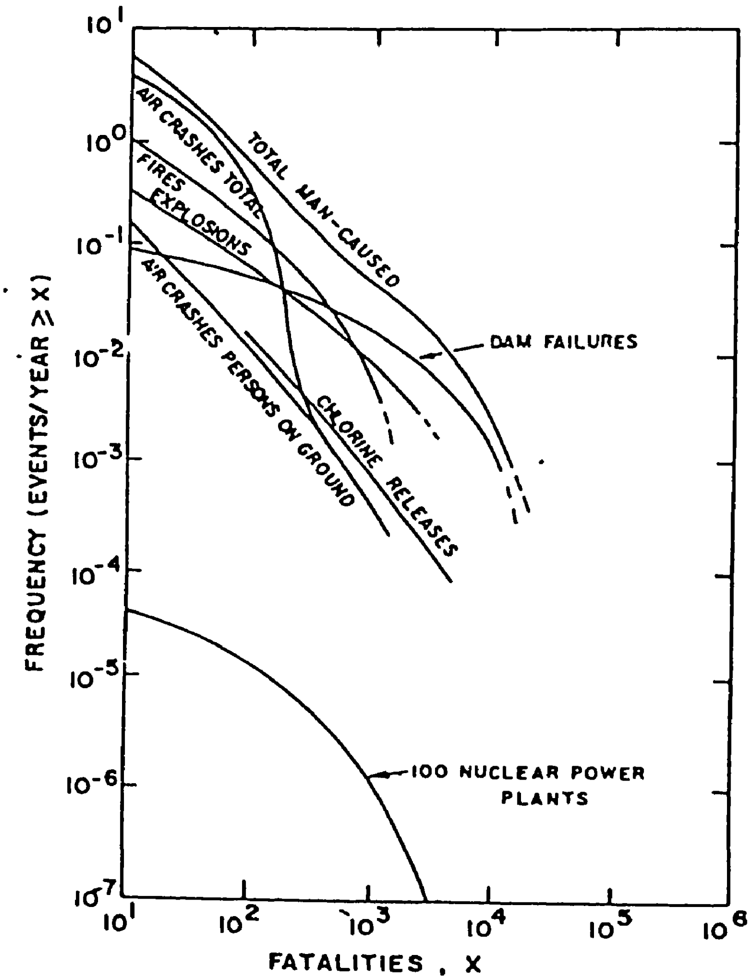
With such exhaustive measures to ensure "safe" functioning of a nuclear plant, one feels that the radiation emitted will be extremely small/negligible. In fact, according to the Department of Atomic Energy the Indian nuclear power plants are well within exposure limits set by the International Commission for Radiological Protection(ICRP). The public exposure to radiation due to nuclear power plants in India is reported to range from 0.02-0.05 milli Sieverts per year whereas the maximum dose stipulated by the ICRP is 1 millisievert per year (Krishnan et al., 1988). However, there are reports that the population living around the Tarapur Atomic Power Station (TAPS) are suffering from adverse impacts of radioactive releases.

For the purpose of this study, it has been assumed that there are no advserse environmental impacts or health impacts attributable to nuclear power plants under normal operations.

3.4.2 The accident scenario

An assessment of accident risks in U.S. Commercial Nuclear Power Plants conducted in the early 1970s indicated that reactor risks are smaller than many other man-made and

natural risks to which individuals are exposed to. This report more popularly known as the Rasmussen report, further states that the largest calculated value of an accident with 2,300 fatalities occurring is only one in ten million (see Figure 3.2). In other words, the chance of a reactor accident is rather remote (Rasmussen, 1981).



Source: Adapted from Rasmussen (1981).

Figure 3.2: Frequency of man caused events involving early fatalities based upon U.S. experience as given in WASH-1400 (Rasmussen Report).

A major reactor accident may result from a random failure of engineered components, oversight in design, human error in operation of the reactor and also due to natural disasters such as earthquakes.

However, at best engineering studies, component redundancy, care in siting and the like can reduce the incidence of events leading to an accident. But the element of human error cannot be played down, as exemplified by the Chernobyl disaster. This disaster occured during a special test to examine whether the residual energy of a spinning turbine could provide sufficient power in case of an emergency shutdown with loss of offsite power. During this test, the operators disconnected safety systems and violated operating procedure. This human error led to 1000 immediate injuries, 31 deaths, 135,000 people evacuated and a financial loss of at least $3 million (Flavin, 1987). Prompt fatalities were limited to 31 due to the dry weather and dispersion of early releases to a high altitude, in addition to the evacuation procedures. According to one estimate, the number of chronic health effects were large including 28,000 latent concerns. Even at distances 1500 km from the accident site, noticeable levels of fallout were measured. The Three Mile Island disaster of March 1979, resulted in two delayed fatalities and thousands were evacuated. Property damage worth 1000 million was incurred (Thomas and Squires, 1989).

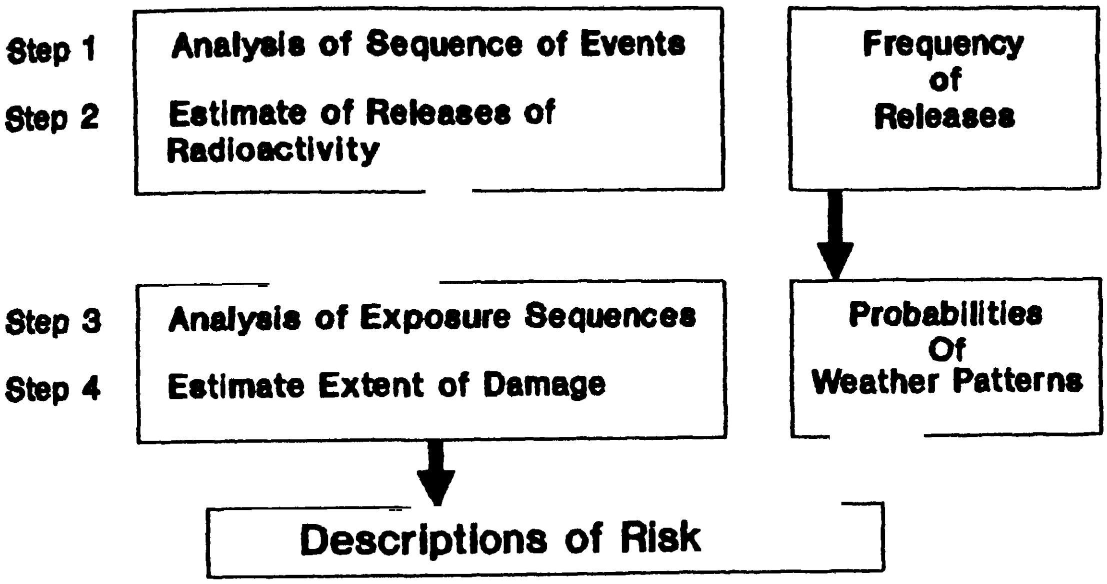
In a study for Ontario Hydro's Pickering Plant, the U.S. Reactor Safety Study was used as a basis for estimating the off-site financial consequences of a severe accident, without consideration of the probablity of occurence of an accident. The consequences considered

included radiation - induced health effects incurred by the public, population evacuation and relocation costs, crops and milk disposal costs, decontamination costs and land area interdiction costs. The study revealed that in the absence of a good emergency response, economic damages of more than $11 billion may be incurred (Lonergan et.al., 1990).

In 1976, the German Federal Ministry for Research & Technology commissioned a study aimed at assessing the risk resulting from accidents in nuclear power plants in the Federal Republic of Germany. A model was developed to map out the consequences of accidents. The risk analyses included a study of the potential sequence of events within a plant and exposures up to the point of damage, estimate the expected frequency of occurrence of this damage. The damage resulting from an accident sequence was defined as the plant internal sequence of events and plant external exposure sequence. The model summary is given in Figure 3.3.

On the basis of steps 1 and 2, eight release categories were identified along with characteristics such as duration of release, release height and energy released. For an analysis of exposure sequences and estimation of damage an accident consequence model was developed with four basic submodels namely

1. The atmospheric dispersion and deposition submodel
2. Dosimetry submodel
3. Protective action submodel
4. Health effects submodel



Source: Bayer et al (1982)

Figure 3.3: The German Risk Study

The model makes computations for 8 release categories, 115 weather sequences, 36 wind directions and 19 sites (with 25 reactor units), i.e. a total of 629280 combinations. Although, the chances of an accident occuring are quite remote, it cannot be discounted completely in the decision making process since the consequences can be catastrophic not only in monetary term but even more so otherwise. It is extremely difficulty to assess the likely damage in the event of an accident and internalise it for the cost computations for generation

from nuclear power. The damage to both physical property and human beings needs to be predicted and a cost assigned to both. The latter is even more problematic due to the philosophical objections to any approach to value human life. In this report, the cost for generation do not account for the chance of an accident and its ramifications thereof.

3.5 Waste management

As mentioned earlier, the wastes generated during normal operations of a plant are either, incinerated or stored in leak-proof trenches. Medium level wastes are stored in reinforced cement concrete vaults and buried at site.

The problem lies with disposal of highly radioactive wastes. These include spent-fuel and by-products of fuel reprocessing. The spent fuel is initially stored underwater at reactor sites in specially constructed pools, to allow much of the radioactivity to decay. It is then stored for 5-10 years prior to reprocessing. On the average high level wastes are stored 20-50 years prior to disposal. Identification of sites which can act as permanent repositories for this waste is an unresolved factor linked to waste management. There are various criteria that need to be examined before a repository site is chosen. These include hydrogeology and stability, mechanical and geo chemical properties, minimum acceptable depth, underground resources and thermal properties of the rock. At present, the scientists prefer

deep geologic disposal of high level wastes. The rationale for this preference is that radio-active waste needs to be isolated from the human environment for a period of time and geological disposal will also ensure that subsequent release of radionuclides from the repository will not result in unacceptable radiological risks, even in the long term.

At present, there are no away from reactor `(AFR)' facilities in India to deposit the high level wastes that will be generated when a plant is ready for decommissioning. The cost of developing sites and transporting wastes to these sites is also subject to considerable variations. The costs of waste disposal are not currently being accounted for in India. According to one estimate, the costs for high level waste disposal are 15-22% of the decommissioing costs.

3.6 The decommissioning debate

The current debate on decommissioning of nuclear power plants is concentrated on the economics of it. However, it is likely to gain a social context.

The International Atomic Energy Agency(IAEA) has outlined three stages of decommissioning (Pasqualetti, 1991). In stage 1, defuelling of the plant is undertaken. This process normally requires 5-7 years for completion. In the next stage all plants and buildings outside the biological shields are removed. This process also takes five to seven years. In the final stage, the reactor is

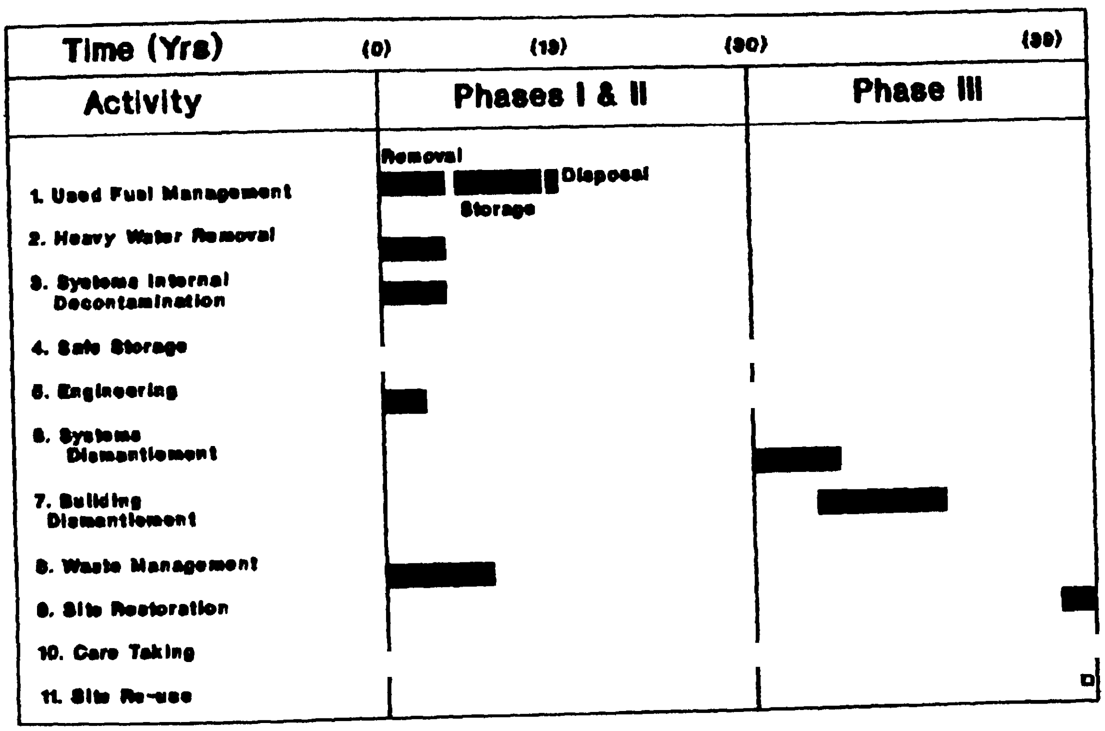
dismantled and the site is released for unrestricted use in a phased manner. If all three stages take place continuously, the entire task should take 17 years. However, complete removal may take longer than 17 years, till the radioactivity has reached benign levels. It is important to note that there is a trade-off between the policy of waiting for a substantial reduction in radioactivity before decommissioning and a prompt removal strategy, in terms of costs. In the latter the costs are relatively low but the probability of harm is very high, whereas in the former the costs are extremely high and damage from radioactivity is low.

In the United States, however, the strategies adopted for decommissioning are different from the IAEA's. In particular, these strategies include SAFSTOR, DECON, ENTOMB. In SAFSTOR, which lasts about 30-60 years, the non-essential systems are decontaminated and removed and only essential systems such as those required for storage of spent fuel or other wastes, security and monitoring systems are maintained. These are put in protective storage. At the end of the required time span, these are dismantled.

In DECON, all the nuclear structures are decontaminated and there is a prompt decommissioning of the plant to a `greenfield' situation. However, the DECON mode presupposes the availability of a high-level radioactive waste facility.

In the ENTOMB method, barrier is built and radioactive components are either removed from the site or placed in the entombment for a period of 30-100 years. The site is decommissioned at the end of this period.

CANDU reactors of Canada will be decommissioned in three phases, as described earlier. The first two phases will last about 30 years. A typical decommissioning schedule is given in Figure 3.4.



Source: Jayawardene and Stevens-Guille (1991)

Figure 3.4: A typical decommissioning schedule

An important aspect related to decommissioning is that of disposal of highly radioactive wastes. Development of waste respositories is an essential prerequisite for any decommissioning activity. Waste disposal costs constitute approximately 15-22% of the decommissioning estimates (Strauss and Kelsey, 1991).

The other important issue is that of estimating the cost. There is a high degree of uncertainty attached to it. There are three ways of estimating decommissioning costs, namely

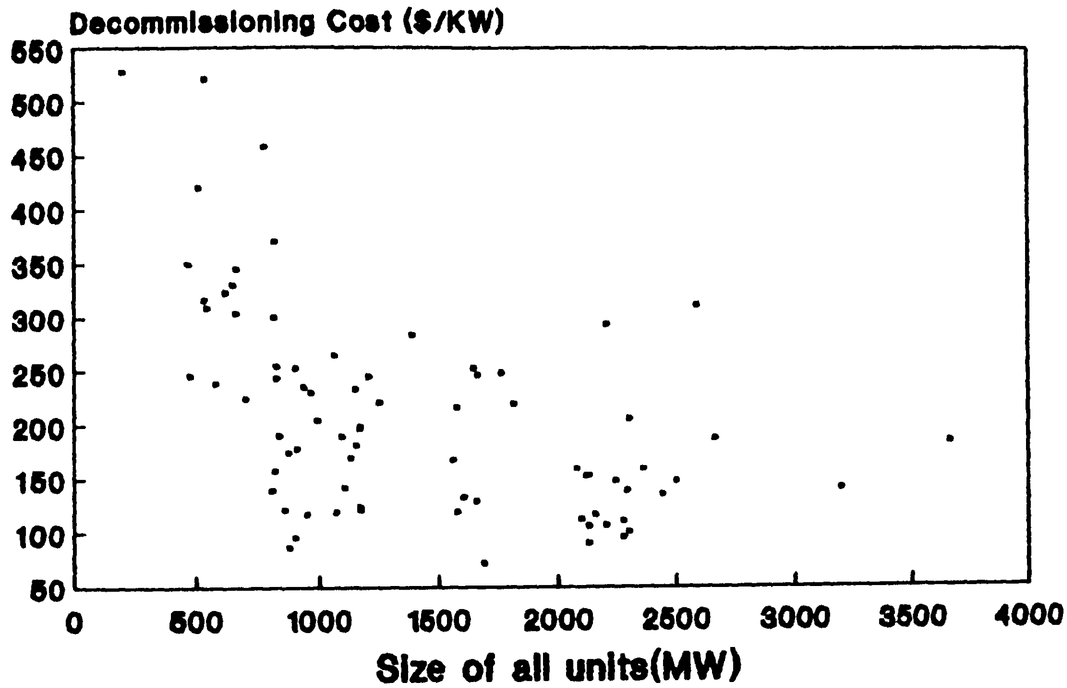
(i) Scaling up costs of small research reactors

(ii) Taking a fixed percentage of the capital costs and

(iii) From site-specific engineering studies

The site-specific studies have to account for defueling, removal of all structures exterior to the biological shield. The boiling water reactors (BWRs) are usually considered to be more expensive to decommission than pressurized water reactors, largely because of the differences in the volume of contaminated material. A study by Strauss and Kelsey of 110 nuclear power reactors in the United States, revealed that on an average the cost estimate is $211/KW, the average for BWRs is $248/KW and that for PWRs is $191/KW (Strauss & Kelsey, 1991). These averages may be a little misleading, since the costs estimates are based on different criteria for decommissioning. A majority of the utilities have indicated that they would opt for prompt removal of the reactors. For some plants, a site-specific evaluation of costs was undertaken, while for others generic studies were used as a basis.

It is well established that multiple unit plants show some decrease in costs per KW, over single unit plants. In addition smaller plants cost more to decommission than do larger plants (Figure 3.5).



Source: Adapted from Strauss and Kelsey (1991)

Figure 3.5: Decommissioning cost per kW by facility size

Once the economics of this issue is settled, the funding plans for the same need to be considered. These plans include methods such as full prepayment, insurance or surety bonds and external sinking fund reserve. Full prepayment refers to funding the entire current cost of decommissioning immediately, and is ruled out as it is highly expensive. The second method viz. insurance is also

not viable as decommissioning insurance is not yet currently available. The sinking fund approach is the only alternative whereby annual contributions are accumulated.

In the Indian case, the external sinking fund approach is used and an amount of Rs. 0.01/kWh is set aside for this purpose. In comparison international experience suggests that the costs are more likely to be approximately 30 paisa per kwh. For details see Section 3.7.

3.7 Economics of nuclear power

It is generally claimed that cost of generation from nuclear sources is quite comparable to the costs of coal based generation (DAE, 1985).

Recalculation of the cost estimates for nuclear has been undertaken here, using the data available for the Madras Atmoc Power Station, Unit 1 (Table 3.3). All the costs have been computed in 1990/91 prices using the wholesale price index.

The cost build-up used for re-computations is given below:

Capital costs

These costs include expenditure on buying a site, developing it, constructing buildings, cost of the reactor, boiler, auxiliaries, the turbine generator, the electric power systems, instrumentation, various

Table 3.3: MAPS Unit 1: Break-up of costs (Rs.lakhs) (In 1983 Prices)

Site and Improvement	57
Building and Structures	1232
Reactor boiler and auxillaries	2552.9
Turbine generator and auxillaries	1752.9
Electric power system	721.15
Instrumentation and control	780.84
Common processes and services	1004.61
Construction plant and facility	489.95
Engineering	569.3
Foreign travel and customs duty	640.5
Freight and Insurance	156.25
Commissioning	762.5
Fuel	612 (5.15%)
Heavy water	390 (3.28%)
Field Management	350
Others*	381.02
Total	11882.92

* Others category includes housing, receipts and recovery and the contingency allowance.
Source: DAE, Note on MAPP I cost, PPED/00040/84/B/5062.

engineering requirements, and costs for commissioning a plant.

These costs comprise about 90% of the total costs of setting up a nuclear plant.

In addition, cost of initial fuel and heavy water requirements are also capitalized. It may be mentioned that the initial requirements for a 235 MW reactor are 61 tonnes of uranium and 250 tonnes of heavy water.

Operating costs

Annual fuel and heavy water requirements alongwith the wages and salaries bills comprise the annual operating cost.

The wages and salaries bill is assumed to be 2.5% of the annual capital costs.

Decommissioning estimates

These were based on the U.S. experience. Strauss and Kelsey have collected information on how decommissioning costs are treated by 37 regulatory agencies in the U.S.. It covered about 110 nuclear reactors. From this study, the cost of a 470 MW PWR plant, Ginna, was used for estimating for the Indian case. The total cost for Ginna is estimated to be $164 million (1989 prices). This is a very site-specific estimate and is based on prompt removal of the reactor. This estimate may prove to be a lower bound for India, in light of the lack of experience and technical skills available within the country.

A cost of $164 million translates to $349/KW or Rs. 5933/KW. Assuming an escalation of 2% in real terms in the aggregate estimates, the annualized decommissioning cost is Rs. 1239/KW in 1990 prices or Rs. 0.30/kWh, given a utilization of 4100 kWh/kW. For a utilisation of 5,500 kWh/kW, the estimate is Rs.0.22/kWh. The assumptions used for computing the cost of power generation from nuclear plants is given in Table 3.4.

Table 3.4: Assumptions for computing cost generation from nuclear power

1. Size of the plant (MAPS 1)	235 MW
Capital costs (1990 prices)	Rs 801 crores
2. Annual O & M costs (1990 prices)	Rs 51 crores
3. Interest during construction	
- for a 9 year period (1990 prices)	Rs 81 crores
- for a 15 year period (1990 prices)	Rs 96 crores
4. Decommissioning charge (1990 prices)	Rs 9720/kW
5. Annual utilization	4100 kWh/kW
6. Economic life	25 years
7. Rate of discount	12%
8. Annualized capital costs for a nine year period (1990 prices)	Rs 234 crores
O&M costs	Rs 250 crores
9. Cost of generation	
- for a 9 year construction period	Rs 2.04/kWh
- for a 15 year construction period	Rs 2.89/kWh

Cost of heavy water

Heavy water is costed at Rs. 7220/kg and only a leasing charge for the same is included in the cost computations of DAE. On the other hand, according to the Comptroller and Auditor General's Estimates (Reddy, 1988) the cost of heavy water is Rs. 13,800/kg. Furthermore, it is more realistic to take it as a full cost while computing the cost of generation from nuclear sources rather than as a leasing charge.

__Decommissioning estimates__

The DAE charges Rs. 0.01/kWh for funding decommissioning. The costs, according to our estimates is Rs. 0.30/kWh.

3.7.1 Results

Table 3.5 summarizes the cost of generation under various scenarios.

Table 3.5 : Cost of generating electricity

	Assumptions	Rs./kWh
1. DAE estimate	. 9 year construction period . utilisation 5500 kWh/kW . IDC @ 35% (cumulative)	0.83
2. TERI estimate		
Scenario I	. 9 year construction period . utilisation 5500 kWh/kW . IDC @ 79.4% (cumulative)	2.04
Scenario II	. 9 year construction period . utilisation 4100 kWh/kW . IDC @ 79.4% (cumulative)	2.74
Scenario III	. 15 years construction period . utilisation 5500 kWh/kW . IDC @ 94% (cumulative)	2.15
Scenario IV	. 15 years construction period . utilisation 4100 kWh/kW . IDC @ 94% (cumulative)	2.89

The results clearly indicate that the generating costs for nuclear plants are prohibitive, if one takes cognizance of the fact that the gestation period lasts for 15 years and that a more realistic utilisation rate of these plants is 4100 kWh/kW or 47% capacity factor.

However, even if it is assumed that in the future 235 MW plants can be constructed in 9 years and thet they have a high capacity factor of 62.7%, the costs for generating 1 kWh is likely to be Rs.2.04, in 1990/91 prices. It is important to reiterate that the basic assumption is that heavy water is purchased rather than leased and that the decommissioning charge is Rs.0.22/kWh and not 1.1 paisa/kWh.

The cost of Rs.1.68/kWh does not adequately take care of the chance of an accident at a plant. Although the probability of such an event occuring is rather low, the consequences attached to it have wide ramifications including damage to property and human costs.

CHAPTER 4

Coal Based Power Plants - Environmental Aspects

4.1 Introduction

Indian power generating capacity, which is mostly owned and operated by utilities, has grown at an annual average rate of 9.8 per cent since 1950. Thermal power capacity has grown at an identical rate over the same period. The share of thermal power plants over this period has declined marginally from 67 per cent to 63 per cent. Data for 1988-89 shows the share of coal fired thermal power stations to be around 38 GW out of a total installed capacity of 60 GW.

Human health and ecological impacts are the major risks involved with the operations of a power plant and these need to be estimated, in addition to the costs of generation. Contamination of the environment occurs through the medium of land, air, and water.

A major pollution problem associated with coal plants is that of the disposal of large quantites of ash generated. Given the high percentage of ash in Indian coals, it has been estimated that between 30-40 million tonnes of ash are generated annually (Gupta et al, 1992). Further, given the capacity additions planned in the coming years and the land requirements of 0.4 ha/MW installed capacity, it is expected that by the year 2000, about 28,000 ha of land will be required for storage of ash. The increasing pressures on the limited land

available in India should only serve as a catalyst in the identification and adoption of economic uses of this pollutant. While limited application has been found in the brick, cement and road construction industries, the quantity thus utilized vis-a-vis the quantum generated is negligible (currently a mere 3.5 per cent is utilized in India). Further, as a consequence of leaching, pollutants enter the surrounding water bodies; the extent of which remains unquantified. Hence, the pollution of land, and consequently water, due to ash disposal remains difficult to estimate, let alone placing a monetary value on it.

Air pollution occurs as a result of the emission of oxides of sulphur (SO_x), oxides of nitrogen (NO_x), particulates (SPM), carbon dioxide (CO_2), hydrocarbons (HC), radionucleids and aldehydes. However, the study restricts itself to the impacts of the emissions of SO_x, NO_x and SPM only. The polluting gases have, individually, an impact on both human health as well as the ecosystem; the extent of which is determined by the dosage received, the time span over which it is received and the average well-being of the recipient population. Further, the interaction of a pollutant with another often results in chemicals/pollutants that enhance the impact on human health.

Pre and post combustion control measures exist for all the major pollutants. At present, the installation of electrostatic precipitators (ESP) for the control of SPM

emissions are mandatory in India. The average cost of SPM control by ESPs is approximately 1 per cent of the cost of generation. ESPs usually operate at efficiencies of 99 per cent and above; the efficiencies generally being relatively insensitive to particle size but grade efficiency curves indicate a minimum in the 0.2-2.0 micrometers range (Wallin, 1986). However, the efficiency of particulate removal below 0.1 um is poor and given that about 95 per cent of the flue gas comprises of particles with diameter less than 0.1 um, it implies that only about 5 per cent of the particles are actually removed, though the mass equivalent is about 99 per cent (Priest, 1973). This is important given that the smaller sized particles penetrate deeper into the lung and therefore can be more toxic (Ottinger et al, 1990).

Similar mandates for the installation of control equipment for SO_x and NO_x emissions are yet to be promulgated. For SO_x, post combustion abatement using a flue gas desulphurizer (with efficiencies in excess of 90 per cent) is an expensive option (about 25-30 per cent of the cost of generation). Given the low levels of sulphur in Indian coals (around 0.5 per cent) and the high associated costs, the installation maybe limited to regions already stressed by high levels of SO_x and/or TSP emissions. Post combustion NO_x control can be achieved with selective catalytic reducers, with efficiencies greater than 80 per cent. Cost of NO_x removal adds about 6

per cent to the cost of generation. The validity of installation of SCRs is primarily dependent on whether lower levels of No_x emissions are achievable with improved combustion practices. Currently, pre combustion control options, e.g. low NO_x burners, are being installed in some plants. Though the costs are low (approximately 0.2 per cent of the cost of generation), the removal efficiencies of low NO_x burners is below 50 per cent.

Devices used for the control of SO_x and SPM yield solid wastes, wet or dry, that further require disposal. The abatement, therefore, results in an increase in land, and consequently water, pollution.

Water pollution is generally a result of the discharge of boiler blowdown and cooling water into the surrounding water bodies. The water generally contains chlorine and other BOD material which affects aquatic life adversely. Part of the problem can be resolved by water treatment practices prior to discharge. The main problem in the estimation of the impacts lies in the absence of any knowledge of the mixing pattern of the pollutants in the water body. Another impact on the water body is as a result of thermal pollution. Elevated temperatures of the surrounding water may increase the metabolic rate of aquatic life or may kill some of the more sensitive species. A higher metabolic rate in turn would have an impact on the quantity of CO_2 emitted. Further, higher temperatures of the water body would lead to a greater dissolution of chemicals and other pollutants, example

grease, leading to greater environmental damage. Thermal pollution can be controlled significantly if cooling systems, e.g. cooling towers, are adopted prior to the discharge.

In the study, an attempt is made to cost the externalities asssociated with thermal power generation and add it to the cost of generation. In cases where the internalization of these externalities cannot be achieved without gross/major assumptions, the study remains confined to a qualitative description of the same.

4.2 Power Plant Description

At the thermal power station, coal is pulverized, fed into the boiler and ignited. The boiler converts the water into steam which is then compressed. This high pressure steam is made to impinge on a turbine which drives the generator to produce electricity. The low pressure steam is then condensed and sent back to the boiler. Figure 4.1 shows a schematic diagram of a power plant.

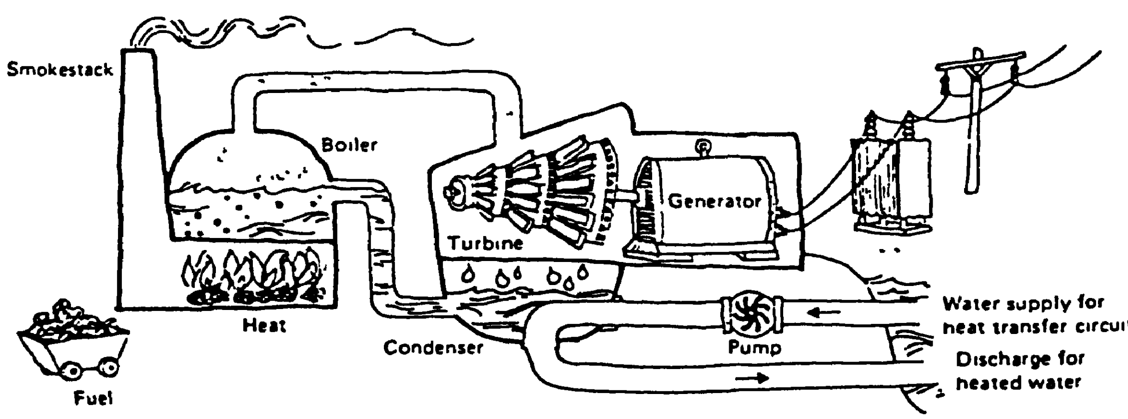


Figure 4.1: Major energy components of a coal based thermal power plant.
Source: Priest, J., Problems of our physical environment (Energy Transportation Pollution), Addision-Wesley Publishing Company, 1973.

4.3 Air, water and solid waste pollution from coal based power plants

4.3.1 Land Pollution

As mentioned earlier, given the high percentage of ash in Indian coals (averaging 40 per cent), significant quantities of both fly and bottom ash are generated annually. About 20 per cent of the ash produced during combustion falls to the bottom of the boiler as bottom ash. The fly ash, captured by the electrostatic precipitators, is collected in hoppers. Depending on the waste management strategy adopted the ash is sent to the disposal site.

The location of ash disposal sites are considered taking into account factors such as surface and underground water pollution, land use, operating costs, and the possibility of atmospheric pollution.

<u>Disposal</u>

Wet Disposal: In wet disposal systems, the ash is transported by slurry pipelines and deposited at the disposal site in a fluid state. Every tonne of flyash requires approximately 8-10 litres of water to convert it to slurry. System differences arise in terms of how the transport water and supernatent are handled in terms of treatment and discharge, recycle, evaporation or impoundment. Land requirements are roughly 0.4 ha per MW installed capacity.

In wet ash disposal systems, fly and bottom ash are transported (often by separate sluicing methods)

to the same or separate ponds. Ponds may be the permanent disposal site for settled ash or the ash may be eventually dredged and disposed in a separate landfill.

The primary advantages of wet systems are that they are simple, relatively inexpensive to operate and normally unobstrusive (quiet, no fugitive dust, no transport traffic). They are also flexible with respect to short term variability of scrubber operation. The main disadvantages are associated with the disposal site. A large disposal area is required due to the large volume of effluents. Preparation of the disposal site requires dams and dykes which increase the cost. Control of leachates (discussed below) and prevention of ground water contamination is more difficult to ensure, and liners are required. Flexibility to long term changes is less.

Dry Disposal: In dry disposal systems the waste is generally transported to and deposited in the landfill as a solid.

Bottom ash is normally transported hydraulically to a dewatering bin or pond; flyash is collected in silos for transport to the disposal site. They are generally transported and disposed separately. Ash is typically trucked to the landfill, dumped, spread and compacted with the use of water. Advantages of dry disposals techniques lie in a lower requirement for land and water and often lower capital costs. Control

of leachates and ground water protection is easier. Site closure and revegetation is simpler and cheaper. The primary disadvantages centre on greater quantities of dust, noise and traffic, and higher operating costs. The most important positive aspects is the ease of reclamation in future use of ash.

Depending on the method chosen, the costs of ash disposal could work out to be Rs.95/ dry ton for ash ponding (assuming 15 per cent solids) and Rs. 125/ dry ton for ash landfill (assuming 65 per cent solids) (Mathur, 1989).

<u>By</u> <u>product</u> <u>utilization</u>: As discussed in Section 4.1 and earlier in this section, the land and water pollution problems associated with the disposal of large quantities of ash have been the prime movers behind the search for alternate uses of the ash. Sale and utilization of the solid by-poducts of coal fired thermal power plants often is an attractive alternative to simple disposal. In the past, the relatively inexpensive disposal option was chosen in preference to the process of marketing, storage and transportation associated with ash sales. In recent years, however, environmental protection Acts (& lobbys) have increased the cost of simple disposal and promoted recovery and reuse. While western nations have found a multitude of uses for ash (current use is around 40 per cent in both UK and France), in India this remains a mere 3.5 per cent (Gupta, et al,

1992). But the situation is not totally devoid of hope. Substantial research on the use of ash in the preparation of building bricks has been carried out. Currently there exist six processes of ash brick making, of which two have been adopted on a commercial scale. The research centres for this work are: the Central Building Research Institute, Roorkee; the Central Fuel Research Institute, Dhanbad; and the Refractories Laboratory (R & D TISCO), Jamshedpur. Two processes (of the four) developed by the C.B.R.I., Roorkee have been commercialized by the Tamil Nadu Housing Board, Ennore and M/s Neyveli Lignite Corporation, Neyveli. Another process is being used to manufacture bricks at Korba, Ramagundam and Singrauli (Sinha, H.P., et al, 1989). The Central Road Research Institute, New Delhi, too, is considering the use of ash as a filler in roads. However, the economic utilization of ash depends on (a) quality of flyash, (b) method of collection and distribution, and (c) the associated cost of collection. Ash use is divided into two categories (i) the use of ash as a substitute for virgin material in construction and fill, and (ii) the recovery of resources from ash in the form of iron, alumina or trace metals. Athough the extraction procedure from the second option will leave a residual material to dispose off, revenue from metal sales might more than offset the cost. If all the high, medium and low value added activities are undertaken, approximately 48 per cent of the total ash

produced can find an economic application. While this is considerable, it still leaves 52 per cent (68 million tonnes) which would have to be dumped and/or landfilled, implying a land requirement of about 15,000 ha. by the year 2000.

Leachate

Leachate is liquid which has passed through or emerged from solid waste and contain soluble, suspended, or miscible materials from the waste. It affects the waste disposal facilities since it may carry potential contaminants into ground or surface waters.

Leachate from landfills originates as precipitation or surface inflow that infiltrates the fill. The quantity is determined by the permeability of the waste and the underlying soil, local climate (precipitation vs evaporation), disposal method (pond or landfill), and site design and management pratices.

The preceding section has primarily focussed on ash disposal methods and the problems associated with the search for alternate uses of ash, given the large quantum that is generated annually as a result of the normal operations of a plant. Estimates of the (environmental) cost involved in the disposal of ash, i.e. in terms of the land and water (through leaching) pollution that occurs, would be a function of the quantity of ash required to be disposed, the method of disposal adopted, and the precautions taken in site preparation (eg. lining) to avoid leaching.

The quantity of ash generated is a function of the plant (and control system) design characteristics, state, and efficiency of operation. The quantum required to be disposed would depend on both the number and type of alternate uses to which the ash could be put. The decision to adopt a particular disposal method hinges on certain factors such as the availability of land, water, capital and infrastructure requirements (transport systems) of that particular system; though this is, in most cases, a management decision. Site preparation involves an additional expenditure.

In India, most of the boilers are wet bottom ones, implying that disposal systems are geared to handle wet ash for either ponding or landfilling. If there is to be an increase in the re-use of ash in the future a major change in the type of disposal system being used would be necessary, since dry ash would be required. Further, the cost of lining disposal sites is site-specific; depending on factors including local topography, labour costs, and the degree of control efficiency desired.

However, costing procedures, in most cases, would overlook the controversy surrounding the price of land (commercial or Government rates) and its shadow price. Hence, even in cases where the most efficient system is adopted and costed, the value of land would require further quantification.

4.3.2 Air Pollution

The potential damage, primarily in terms of health impacts, of the emissions from the power plant are discussed. The ground level concentrations of the gases, i.e. the dosage received by the surrounding populations can be computed using the Gaussian plume dispersion (Appendix 4.B). However, even with ground level concentrations, given the absence of adequate knowledge about the impact of the dose, individual responses were not estimated. This is so because the response is dependent on the general well-being of the receipient population, the concentration received, the duration over which the population is exposed to the dose and the interaction of the pollutant with other pollutants. Given that a reduction in emissions could reduce the possible impacts and that pollution control devices exist, the study has used pollution abatement costs as proxy's for the cost of avoided health damage. Most of the costs are for post-combustion abatement, with the exception for low NO_x burners which is a combustion modification. The relevance of the inclusion/exclusion each control cost in in the overall cost analysis, too, is discussed in the Indian context.

The flue gas from a thermal power plant is primarily composed of SO_x, NO_x, particulates, CO and CO_2. Additionally, radionuclides, hydrocarbons and aldehydes are also entrained.

Particulate Matter

By virtue of their external and internal surface area, particles may absorb chemicals such as carcinogens thus increasing their penetration into the lungs or prolonging their residence time, thereby enhancing the effect of the adsorbed agents. Particles may also serve as condensation nuclei for water and other vapors to produce droplets in which hygroscopic gases such as sulfur dioxide may be absorbed as acids, thereby augmenting the biological effect of these gases. Heavy loading of particulates in respired air may overtax the mucociliary apparatus, thus reducing the rate of removal of irritant chemicals, infectious agents, and carcinogens from the lung.

Fly ash particles are composed of stable elements or compounds that are usually not considered directly toxic in concentrations found in ambient air. However, it is well known that silica, in exposures of sufficient concentration, induces pulmonary fibrosis. It has also been shown experimentally that particles composed of carbon or iron oxide enhance pulmonary tumor production when used in conjunction with polycyclic hydrocarbon carcinogens. It is possible that the chemical nature of the particle is unimportant in this reaction so long as there is sufficient surface area for adsorption of the carcinogen (Priest, 1973).

Physiological differences affect deposition of particles [Saffiotti et al, as mentioned in Coffin and Stokinger, (1987)]. Slower, deeper breathing results in greater deposition of the larger particles in the lungs as compared to rapid, shallow respiration. In experiments comparing 1.6 um and 0.14 um particles, the larger particles were most affected by alterations in breathing, whereas the smaller, in which deposition would be presumably the result of Brownian movement, were much less affected [Brown, as mentioned in Coffin and Stokinger, (1987)]. Constriction of the upper airway as the result of exposure to irritant chemicals tends to result in greater deposition in the nasopharyngeal region and consequently less penetration into the lungs. Inhaled chemicals, even if insoluble in the lung, eventually reach the gastrointestinal tract, where there is a chance for solubilization in gastric fluids and subsequent chemical reaction. Spontaneous disease and exposure to many inhaled chemicals slows clearance by inhibiting the movement of cilia or through clogging the respiratory tract by excessive production of mucus. However, a portion of the insoluble material is slowly cleared from the lung by penetration of the respiratory epithelium, thereby gaining entrance to the interstitial area and lymphatics. Chemicals soluble in the respiratory tract are quickly absorbed at all levels of the tract from the nose to the pulmonary alveoli. Therefore, exposure to

chemicals by inhalation results in possible toxic interaction at many levels and compartments of the body.

While it is convenient to consider "particulates" as a single class for control purposes, it is impossible to discuss the toxicological potential of source material as though it were a single entity, as for instance nitrogen dioxide. The particles in the air are derived from innumerable natural and man-made sources, each contributing differing physical and chemical properties to the mix. The potential for biological activity of a given particle is governed not only by physical and chemical nature of the fuel, the combustion process, but also by its opportunistic ability to interact with other environmental pollutant substances capable of chemical or physical interaction.

The biological activity of the average of the particles in various locations then must of necessity vary because of differing pollutant source profiles for any given community. These variations are expressions of both quantitative and qualitative differences, as for instance the relative amount of sulfuric acid mist, sulfates, or other reactive substances in the particulate mix or the relative amounts of specific carcinogenic compounds in the organic fraction of airborne particulate.

High particulate concentration tie ups with high sulphur oxide levels often result in effects not visible

otherwise. High pollution levels combined with abnormal weather (i.e. stagnation of air) often results in increased health effects. Guidelines (due to inaccuracies) to health effects (Priest,1973) are:

(i) at concentrations of 750 ug/m^3 and higher for particulates on a 24 hour average and SO_2 concentrations of 715 ug/m^3 and higher, excess deaths and considerable increase in illness could occur;

(ii) concentrations above 300 ug/m^3 for particulates persist on a 24 hour average and are accompanied by SO_2 concentrations exceeding 600 ug/m^3 over the same period, chronic bronchitis patients suffer a worsoning of symptoms.

SPM Control: There are two broad categories for control of particulates from stationary sources : wet scrubbers and dry abatement techniques.

Wet scrubbers are devices where particles are removed by washing with an appropriate scrubbing liquid. The mechanism controlling the removal is inertial impaction, except in a few cases where simple diffusion and condensation may be important. The performance of the scrubber is limited by the maximum value of the inertia parameter, which is in turn related to the pressure drop over any stage. Larger pressure drops require more energy and therefore the system is costly to operate but might be necessary in cases where efficient collection of smaller particles is essential.

Dry abatement techniques include mechanical collectors, electrostatic precipitators (ESPs) and fabric filters. Mechanical collectors usually of the cyclone type are based on the principle of inertial separation of particles.

ESPs remove particles from flue gases by the use of electrical forces in a step-wise fashion. First, the particles are charged, then passed through an electrical field and captured and agglomerated onto a collection of plates and wires, from which they are mechanically removed by rapping or washing. Modern ESPs are normally designed for gravimetric efficiencies of the order of 99 per cent (Wallin, 1989) and in service can achieve this providing there is good maintenance. Pressure drops across the units and running costs are low; but capital costs are high. The efficiencies are relatively insensitive to particle size but grade efficiency curves indicate a minimum in the 0.2-2.0 micrometers range (Wallin, 1989).

Fabric filters are preferred for their high overall collection efficiency, which is maintained over a wide range of particle sizes. For sub-micron particles, bag filter systems in terms of collection efficiency are superior to all other control technologies. With woven fabrics, the dust layer itself builds up and improves collection efficiencies. The depth of the material is important in the case of non- woven fabrics and is used in applications using high gas flow rates.

The cost of control per unit electricity generated for a typical power plant has been computed to be Rs.0.02 per kWh (TERI, 1991).

Sulphur Oxides

While SO_2 itself is not considered to be one of the major causes of air pollution related health effects, they react in the atmosphere to form sulphates, which is believed to be toxic to humans. Sulfur dioxide is an irritating gas for the conjuctiva and upper respiratory tract and throat. Mortality is generally associated with congestion and haemorrhage of the lungs, pulmonary edema, thickening of the interalveolar septa, and other relatively nonspecific alterations of the lungs.

Particulate interaction and elevated relative humidity enhance the reactivity to sulfur dioxide. Sulfuric acid mist and certain particulate sulfates induce a greater response than sulfur dioxide by itself. Since the rate of conversion of sulfur dioxide to its oxidation products is influenced by photochemical activity and the presence of metallic catalysts and other factors, these interactions are important in air pollution control since it is possible for the rate of conversion of sulfur dioxide to acid sulfates to have greater health significance than the concentration of sulfur dioxide in the air.

A number of investigators have exposed human volunteers to sulfur dioxide, sulfuric acid mist, and

aerosols of sulfate. Lack of consistency concerning method of exposure, concentration, duration of exposure, and parameters examined makes interpretation of results difficult.

Sulfur dioxide is absorbed rapidly in the nasopharynx of man. The effect of sulfur dioxide on the clearance of mucus from the airway has been studied by Cralley (as mentioned in Coffin and Stokinger, 1987) who noted a dose related slowing of clearance after exposure to 10 ppm for 1 hour. Thus, increased frequency, diminished tidal volume, and decreased respiratory and expiration flow rates have been noted for exposure to sulfur dioxide and sulfuric acid mist [Amdur, as mentioned in Coffin and Stokinger (1987)]. Frank et al. and Frank [as mentioned in Coffin and Stokinger (1987)] found a definite and uniform increased flow resistance at 5 ppm which appeared dose related.

Alterations of the state of human health most likely to be attributable to exposure to sulfur dioxide, sulfuric acid mist, and/or acid sulfates are irritation of the upper respiratory tract and conjuctiva, acute aggravation of acute cardiopulmonary disease, and possibly exacerbations of asthmatic attacks and chronic obstructive pulmonary disease. Meteorological conditions and the concentration of primary pollutants might favor the development of sulfuric acid mists and specific acid sulfates of small particle size which are capable of eliciting pulmonary changes sufficient to

cause death in susceptible people and cattle whose respiratory reserve was possibly reduced due to obesity [Coffin, as mentioned in Coffin and Stokinger (1987)].

It is clear however that sulfur dioxide, sulfuric acid mist, and various other sulfur compounds together with nitric oxide, heavy particulate loading, water vapor (fog), and relatively low ambient temperature were associated in the atmospheres in which acute mortality has occurred in man (Air Quality Criteria for Sulphur Oxides, 1970) and domestic animals [Coffin, as mentioned in Coffin and Stokinger (1987)]. However, knowledge of the conditions which brought about the mortality is based mostly on post hoc speculation.

Some conclusions on the effect of SO_2 (Priest, 1973) that do emerge are:

(i) at concentrations of about 500 ug/m^3 of SO_2 (24 hour mean) with low particulate levels, increased mortality rates might occur;

(ii) at concentrations of about 715 ug/m^3 of SO_2 (24 hour mean), accompanied by particulate matter, a sharp increase in illness rate for patients over the age of 54 with severe bronchitis may occur;

(iii) at concentrations of about 120 ug/m^3 of SO_2 (annual mean), accompanied by smoke concentrations of about 200 ug/m^3, increased frequency and severity of respiratory diseases in school children may occur.

Below is a table documenting some research findings of the impact of SO_x on man:

Table 4.1: Observed health effects from exposure to oxides of Sulphur

Concentration (ppm or ug/m^3)	Length of exposure	Observed effects
0.0035-0.1 ppm (SO_2)	3 years and longer	Excessive acute respiratory disease in communities heavily polluted with SO_2 and sulphates
0.003-0.2 ug/m^3 H_2SO_4 (aerosols)	3 years and longer	Excessive acute respiratory disease in communities heavily polluted with SO_2 and sulphates
>0.02 ppm (SO_2)	260 days	Community mortality 2% greater than expected
0.03-0.05 ppm (SO_2)	Daily	Condition of bronchitic patients worsened by high levels of SO_2 and smoke
0.2 ppm (SO_2)+ 0.6 mg/m^2 H_2SO_4	3,6,9,12,15 mnts	Increased optical chronaxie
0.3-1 ppm (SO_2)	20 seconds	Attentuation of alpha wave in encephalographic measurement.
0.3,1.0,3.0,4.2, 6.0 ppm SO_2	Upto 120 hours continuous	Possitive correlation of S-sulphonate plasma levels with atmospheric SO_2
0.52 ppm (SO_2)	15 minutes	Increased eye sensitivity to light during dark adaptation.
0.35-5 ug/m^3 (H_2SO_4)	5-15 minutes	Reflects bronchoconstriction, all levels shallow rapid breathing:decreased minute volume, 5 ug/m^3 level.
0.6-2.4 ug/m^3 (H_2SO_4)	60,90,120 minutes	Transient increased sensitivity to light
1-5 ppm (SO_2)	10 minutes, 15-20 minutes rest; 30 minutes, 1 month apart	Increase pulmonary airway resistence
1,5,25 ppm (SO_2)	6 hours	Nasobronchial reflects bronchoconstriction, all levels:decrease in nasal mucus flow rate, 5 and 25 ppm: no change in closing volumes
1.6 ppm (SO_2)		Lowest concentration resulting in bronchoconstriction.
1.6-10 ppm (SO_2)	5 minutes +/- NaCl aerosol	Increased pulmonary airway resistence
2,5 ppm (SO_2)	3-10 minutes	Increased airway resistence
3-30 ug/m^3 (H_2SO_4)	10,60 minutes +/- water vapour	Humidity increases irritancy of sulphuric acid mists.

Source: Coffin and Stokinger (1987).

$\underline{SO_2}$ Control: Pre-combustion options are relevant only for SO_x control and focus on removing or reducing the sulphur content of the fuel. The potential for the physical removal of sulphur from coal is critically dependent on the proportion and size distribution of the pyritic sulphur in the coal. The pyrite is removed by simple froth flotation, two-stage flotation or gravity methods.

Removal of SO_2 during the combustion stage can be achieved by the injection of limestone into pulverized fuel flames. Staged combustion, with the associated lower flame temperature, improves SO_2 removal efficiencies.

The wet scrubbing processes involve an aqueous slurry or an aqueous solution as the scrubbing agent. The wet scrubbing flue gas desulphurization (FGD) can be divided into two categories. The non-regenerable systems are defined as those which require the scrubbing media to be disposed off as solid or liquid wastes. In the second case of regenerable process, the scrubbing medium is regenerated and recirculated, and the SO_2 recovered from further processing to sulphuric acid or elemental sulphur. Several processes exist for this kind of scrubbing eg. Wellman-Lord, Magnesium Oxide, Citrate and Ammonia Scrubbing processes.

Dry FGD is a generic term applied to processes in which the SO_2 reacts with a dry solid absorbent. Dry FGD processes fall into three categories : (a) dry sorbent injection, (b) spray drying, where the absorbent

material is injected as a solution or a suspension, and (c) dry absorption, where the SO_2 is collected onto a bed of the sorbent. The process may be regenerable, depending on the sorbent used. It has certain advantages of a dry end product, less complex than the wet process and over 70 per cent efficiencies achievable (Wallin, S.C., 1989).

The control cost for a typical power plant per unit electricity generated has been estimated as Rs. 0.40 per kWh (TERI, 1991). The estimate is based on cost estimates of a 1988 EPRI study, where capital and O&M costs have ben quoted as Rs.4550/kW installed capacity and Rs. 0.468/kWh, respectively) for India. This might vary marginally with specific plant operations.

Nitrogen Dioxide

A number of oxides of nitrogen are present in ambient air. Nitric oxide (NO) is formed during the combustion of any material at high temperature by the oxidation of atmospheric nitrogen as well as due to the presence of nitrogen in the fuel, most of which (99 per cent) gets converted into NO_2. NO is oxidized to nitrogen dioxide (NO_2) in the atmosphere. This oxidation of nitric oxide to nitrogen dioxide is particularly rapid in the atmospheric photochemical process.

Nitrogen dioxide is the major toxicant of this group because of its relatively high toxicity and its pervasiveness in ambient air. A number of

occupational diseases syndromes and pathological maladies are attributed to it e.g. silo fillers' disease and bronchiolitis obliterans.

While nitrogen dioxide is a serious human health hazard with death-threatening potential from exposures of short duration (probably as short as 3 seconds at concentrations of 50 ppm and upward or of 10-40 ppm over a longer duration), such acute effects are generally impossible at the relatively low concentrations present in ambient air. Nitrogen dioxide appears to exert its toxic action mainly on the deep lung and peripheral airway, although distal effects probably occur.

Experimental studies conducted by von Nieding et al. [as mentioned in Coffin and Stokinger (1987)] in human volunteers have yielded positive results after exposure to as low as 5 ppm for 14 minutes. Studies were performed on normal human volunteers and chronic bronchitics [von Nieding, as mentioned in Coffin and Stokinger (1987)]. In both groups arterial oxygen partial pressure (PaO_2) decreased after exposure to 4 ppm nitrogen dioxide for 15 minutes but not at 2 ppm.

A great deal of interest has been expressed in the possibility that exposure to nitrogen dioxide or nitric oxide may induce methemoglobin formation. Since methemoglobin does not bind oxygen, its formation would impair the oxygen-carrying capacity of the red blood cells to a degree commensurate with its concentration.

Information on the long term effects of exposure to NO_x is limited and hence only short term exposure limits have been suggested. Nitrogen dioxide concentrations of 940 ug/m^3 was an estimate of the lowest level at which adverse health effects due to short term exposure to NO_2 could be expected to occur. One study did reveal adverse effects at a concentration lower than the norm specified, but the WHO task group felt that this required confirmation (WHO, 1981). Adopting a safety factor of 3-5 per cent, a maximum one hour exposure of 190-320 ug/m^3, not to be exceeded more than once a month was set. A table for NO_x effects is given below:

Table 4.2: Summary of toxic effects of Nitrogen Dioxide (long and short-term intermittent doses)

NO_2 (ppm)	Length of exposure	Observed effect(s)	Species
1.6-5	~2 minutes	Increased airway resistance	Human subjects W/chronic respiratory disease
5	15 minutes	Decreased diffusion capacity	Healthy human subjects
0.4-2.7	180 days	Increase in blood lipids, lipo-proteins and cholesterol	Human occupational exposure

Source: Coffin and Stokinger (1987).

<u>NO_x</u> <u>Control</u>: Most of the processes for NO_x removal from boiler flue gas have not reached commercial status yet. Dry methods for NO_x removal include catalytic reduction, non-catalytic reduction, absorption by solids and catalytic decomposition. Wet methods of NO_x removal are

limited by the relatively inert nature of NO. The wet processes involve the simultaneous removal of NO_x and SO_x, as SO_2 absorption can aid in NO removal. Selective catalytic reduction of NO_x with NH_3 requires clean gas feed (i.e. some degree of particulates removal is necessary), some auxiliary heating maybe required and removal efficiencies greater than 80 per cent (Wallin, 1989) achieved. The advantages of the selective non-catalytic reduction are that it operates at full particulate loadings and requires no additional post-boiler processing equipment.

To prevent the formation of NO_x within the boiler, modifications are made in the combustion process. These are (a) low excess air operations, (b) staged combustion (c) flue gas recirculation, (d) reduced air preheat and water injection and (e) low NO_x burners. Several types of low NO_x burners have been developed. Here the burners introduce fuel with the minimum of combustion air into a sub-stoichiometric primary combustion zone. Combustion is achieved under controlled conditions which do not support high flame temperature. More air is introduced downstream of the primary zone to complete combustion.

The control cost of NO_x using a SCR and low NO_x burners has been estimated at Rs. 0.12 (TERI, 1991). The estimate is based on cost estimates of a 1986 CDA/ERL study done by Scharer and Haug, where capital and O&M costs have been quoted as Rs.947/kW installed capacity and

Rs. 0.14/kWh, respectively) and Rs.0.004 (as quoted in A.C.Stern,1987), respectively, per kWh generated. Given the absence of any record/measurement of NO_x emissions, the quantum emitted is a theoretical estimate. Nevertheless, the costs involved are sustantial and given that the same can be achieved with better operations, i.e. better combustion practices, the compulsions to install a SCR could be non-existant. But in cases where the background pollution levels are high and further additions, however marginal, could prove to be harmful, the installation of a SCR might be necessary. The other air pollutants, emitted in small quantities, do have certain health impacts. Radionuclides are mutagenic and/or carcinogenic. If soluble, they affect the bones and if insoluble, they affect the lungs. Given that they are inherent in the coal, their removal is rather difficult. Emissions of aldehydes can be reduced by efficient and complete combustion. Depending on the quantum of emission and the metal involved, they may affect the lungs. Complete and efficient combustion can reduce the quantum of hydrocarbons produced. Apart from being carcinogenic, these pollutants also cause shedding of tears, coughing, headaches, sneezing, bronchitis, and nervous weakness. In the atmosphere they are responsible for the formation of photochemical fog.

A study conducted at the KEM Hospital (Kamat, et al, 1984) is the most valid for impact studies in India. The study incorpoated variables such as housing

conditions, monthly income of family, age, sex and duration of residence, in determining the socio-economic profile of the population. Tobacco intake was classified on the basis of chewing and smoking. A prospective survey on 4129 subjects in 3 urban (high, medium and low as per SO_2 levels) areas and a rural community conducted at the initiation of the study showed an initial prevelance of dyspnoea as 8.0, 5.9,3.2 and 5.5 per cent respectively. Chronic cough revealed figures of 5.4, 3.0, 1.4, and 3.3 percent, while intermittent cough had figures of 15.6, 5.8, 0.4 and 3.7 respectively. Over the 3 years (between 1978-80) as part of the study, 53-60 per cent of urban and 44 percent of rural subjects were reassessed. The results were rural areas displayed higher morbidities while the `urban low' areas had the lowest rate. The `urban-medium' subjects had a higher frequency of frequent colds and intermittant cough.

The air pollution profile over the corresponding years displayed, the following trends:

(i) The concentration of SO_2 decreased in the urban (high, medium and low areas) but increased in the rural areas.

(ii) Concentration of SPM decreased from the initial year (1970-73) to the year of the initiation of the study but thereafter increased in all the areas.

(iii) Concentrations of NO_2 decreased drastically from the base year, and during the survey years for all region except `urban-high which showed a minor increase during the survey years.

The results of the study revealed that rural subjects showed higher prevalances for all criteria. The rural areas showed an intermediate degree of morbidity. This however, could have been influenced by factors such as absence of sanitation, no protected water supply, poor housing, use of hazardous cooking fuel, poor nutrition etc. These factors in the long run could have accounted for poorer status and lung function of rural residents. The `urban low' continued with lower values. The `urban medium' subjects registered the highest morbidity for common colds and associated coughs at the initial stage though over two years both the polluted areas showed lower morbidity. All urban areas had the same level of incidence of common cough, while it increased in rural areas. The study concludes that there existed a significant relationship between No_2 and frequent colds; coughs with NO_2 and SPM; and chronic cough and dyspnoea to all 3 pollutants. It was felt that there was an association of lower lung functions in normal subjects due to chronic effects of raised air pollutant levels. This trend, however, required further analysis for confirmation. The study also mentions that the populations selected and the predictions were not generally applicable to urban Indian population. Hence, while being one of the first path breaking efforts, its applicability to the country in general is limited.

With a few exceptions, emission control systems for utility power plants have been designed for

the removal of `one pollutant at a time' (eg. ESP for SPM control and FGD system for SO_x control). This is partly because of the piecemeal evolution of the emission regulations. However, operating experience at utilities with multiple-emission control devices has shown that at a given site, certain approaches to controlling the broad spectrum of potential plant emissions are more effective than others. Even if each control subsystem is optimized with respect to collection efficiency, performance, and cost for its own pollutant, the combination of devices that results may not be the optimum for the plant.

The primary objective of this section is to impute a monetary value to the estimates of damage due to air pollution from a thermal power plant. The amount of damage caused would be a function of the dosage received by the surrounding population, as well as the physiological, socio-economic and health characteristics of the recipient population. Health characteristics are not only country specific but also site specific and, therefore, the use of impact relations developed in some of the industrialized countries bear little relevance to a study conducted in India. Even within a country, dose response behaviour would vary between cities. Hence, while the attempt made by researchers at the K.E.M. Hospital, Bombay, is probably the most valid for an impact study in India, it cannot be generalized to all areas with the same degree of accuracy.

Given the site specificity of response patterns, detailed study of the affected region, in terms of both geography and demography, is a pre-requisite. (Details of the procedure involved in the mapping of pollutants onto the population are given in Appendix 4.A).

The dosage received by the population is a function of both the ground level concentrations as well as the period over which the population is exposed. Short-term, high-concentration doses can be as potent, or in some cases more dangerous, than long-term, low-concentration doses. Concentrations sre generally computed on a short term (less than 24 hours), seasonal and on an annual basis. Their levels depend upon both the technical features of the plant (quantity and characteristics of fuel used, type of plant and state of operation, height of stacks, etc.) and atmospheric conditions (wind directions, atmospheric stability, etc.). These can be computed using several approaches, the most commonly used one being the Gaussian Plume Model (described in detail in Appendix 4.B). The model computes ground level concentrations on the basis of exit velocity and temperature of the pollutants, the stack diameter; metereological parameters such as wind conditions, i.e. velocity and direction, ambient temperature; and atmospheric conditions in terms of stability, inversion height, etc.

While the above is the most logical method of determining the damage caused by the power plant, the mapping of pollutants onto the recipient population using

dose response curves is, in practice, virtually impossible to accomplish. Hence, the study confines itself to the computation of ground level concentrations of air pollutants and uses emission standards (set by the Central Pollution Control Board) and the National Ambient Air Quality Standards (NAAQS) to determine the necessity of installing the control equipment. A brief summary is given below.

ESP: The installation of this control equipment has been made mandatory. However, despite high removal efficiencies (over 99 per cent), the emission of about 95 per cent (by number) of the particles is not forestalled, given that the large particles comprise about 99 per cent of the mass but only 5 per cent of the number of particles. Further, it is the smaller particles (below the 0.2 um range), that cause the maximum damage, due to greater penetration into the lungs. Hence, inspite of the emissions being within the prescribed limits, the associated control costs do not cover all the damages, i.e. those caused by the smaller particles is uncosted/unquantified.

FGD: Given the low levels of sulphur in most Indian coals, the emissions of SO_x in most cases are likely to fall within the standards set by the CPCB (in this case the standard is defined in terms of stack height). Damage from SO_x emissions is maximum in areas with heavy

particulate loading, Hence, what will be required is a detailed study of the site, in terms of background levels of SO_x and SPM. The current increase in emissions due to plant operations is to be viewed against the emission standards and NAAQS set and the associated probability of damage. FGDs typically operate at efficiencies of around 90 per cent and contribute to a 25-30 per cent increase in the cost of generation.

SCR: Till recently, NO_x emissions were never considered significant contributors to environmental degradation. However, in recent years increasing attention is being paid to the environmental costs of NO_x emissions and, hence, the necessity of installation of control equipment has to be assessed. Control of NO_x would be based on an assessment of whether the operations of the plant lead to an increase in emissions, beyond the limits defined by the emission and NAAQ standards. Most of the wet scrubbing SCRs operate at efficiencies of approximately 85 per cent and involve an additional expenditure of Rs.0.12/kWh generated (i.e. 6 per cent increase). In contrast, the low NO_x burners, albeit with efficiencies below 50 per cent, impose an additional cost of only Rs.0.004/kWh. Therefore, if the decision is to install NO_x control systems, the reduction required to meet the standards would have to be considered, since this would determine the efficiency of removal and hence the selection of the control system.

4.3.3 Water Pollution

Water use in a power plant affects the environment through both the withdrawal of make up water and the discharge of waste water.

Intake effects:- The withdrawal of water for consumption in the cooling towers and boilers of the plant reduces downstream flows and modifies natural hydrologic cycles and flows in the vicinity of the plant. Damage could either be through (a) impingement of fish or other organisms against the screening structure causing damage or death to juvenile and adult fish by exhaustion, starvation or asphyxiation; (b) entrainment of and/or planktonic organisms through the screening device causing damage through physical, chemical or thermal stresses.

Intake protection devices fall into two categories i.e. collection and removal devices, which are applicable to both entrainment and impingement and behavioural screening applicable only to impingement.

A generalised design and selection procedure involves environmental surveys to determine the characteristics of the hydrology and ecosystem at the site, selection of suitable screening technologies for affected organisms, selection of appropriate methods for excluding or diverting resident and migrating fish and designing cooling systems to provide a tolerant environment for entrained organism. The intake should be located away from critical aquatic habitat areas such as

spawning areas, juvenile rearing grounds etc. and should withdraw water from a depth and distance from the shoreline where aquatic ecosystem activity is minimal.

Discharge effects:- The environmental effects are primarily the chemical or thermal modifications of the receiving waters by the discharge plumes from the cooling towers and the boiler blowdown.

Thermal Discharges: Cooling systems fall into four categories (i) once through (ii) closed cycle (iii) mixed and (iv) dry cooling. All systems must meet the primary performance requirement of maintaining the design condensing pressure at the turbine exhaust. If insufficient cooling capacity is provided, the condensing temperature will rise, the back pressure to the turbine exhaust rises, and the plant output decreases. Therefore, the cooling system must be sized to reject the anticipated heat load under the most adverse (i.e. high temperature and humidity) ambient conditions. The fact that many utilities experience their peak electricity demand during such (high temperature and humidity) periods, compounds the problem.

Thermal pollution of the water bodies occurs with boiler blowdown and/or when condenser cooling occurs. This could affect the aquatic system in a number of ways. For some fish species, warmer water spells disaster in the form of increased mortality rates and increased susceptibility to disease. For some other species, warmer

water could imply a higher metabolic rate which leads to shorter maturing periods and shorter reproduction cycles. This has implications on the food system, as it requires an increased production of food to sustain the increased activity and results in more CO_2 production as well. The increased temperature of the water body changes its physical form i.e. it becomes more viscous. Warmer water also has a decreased ability to absorb CO_2. This could be compounded by increased emissions of CO_2 within the water body itself. In addition, part of the sludge on the water surface dissolves as the temperature is raised leading to a greater absorption of chemicals discharged from the plant by aquatic life.

Once through systems: These systems circulate the water through the plant condensers and return it heated to the environment.

Closed cycle systems: These systems circulate water from the condenser to another device in which the flow is cooled, generally by evaporation to the atmosphere. Some of the commonly used cooling devices are (a) cooling towers (b) cooling ponds and (c) spray systems.

In <u>cooling towers</u>, water is pumped to the top of the tower and allowed to flow down through the fill or packing region to the tower basin. Air currents are passed through the fill area. The fill breaks up the water flow into the droplets, creating a large contact

area between the water and air. As a portion of the water evaporates, the air is heated and humidified while the remaining of the water is cooled. The air flow could be either perpendicular to (cross-flow) or parallel to (counter flow). Both mechanical and natural draft towers are in use. In the mechanical draft tower, the airflow is provided by air induced draft fan. In natural draft towers (concrete, hyperbolic structures) air flow is induced by buoyancy.

Cooling ponds are artificial impoundments created to supply cooling water to essentially a once-through cooling system. The pond assumes a temperature, determined by climatological and plant operating conditions, which is generally higher than that of natural ambient water bodies. Heat is ultimately transferred to the atmosphere.

The spray pond or canal is the least used of the 3 systems. A spray system consists of a series of spray nozzles arranged along a canal connecting the plant cooling water intake and discharge. Dispersion of heat is done by the natural circulations of the atmosphere and circulation induced by the buoyancy of the heated plume.

Mixed systems exist and are essentially once through systems in which the heated discharge flow is partially cooled in a tower spray or pond before being returned to the receiving water in order to meet a stipulated discharge temperature limit.

Dry cooling systems are chosen in cases where water is in short supply or siting flexibility (in terms of proximity to water system) is preferred. Dry cooling systems are of 2 kinds: direct and indirect. In the direct system, the turbine steam is ducted directly to an air cooled cooling tower, where it is condensed and returned to the boiler feed system. In the indirect system, cooling water flows through the condensor in a closed loop to an air cooled tower, where it is cooled and returned to the condenser. The main disadvantage if these systems is the lack of cooling capacity on warm days, and during peak demand periods and hence often have to be supplemented by wet cooling systems.

Heat rejection systems are chosen on the basis of achieving desired environmental standards at minimum cost. The environmental considerations associated with the choice of the cooling system include intake effects, discharge (chemical and thermal) effects, water consumption, boiler blowdown, plume and drift (from cooling tower), land use, noise, aesthetics.

Chemical Discharges: Blowdown from the water subsystems of a thermal power plant is required to control the build up of dissolved and suspended solids and thereby prevent scaling, corrosion and fouling. If the discharge concentration cause the stream concentrations to exceed standards, effluent limitations would have to be set at a lower level. Hence for regulatory purposes,

discharge streams from power plants are divided into several point - source categories of (a) cooling water, i.e. once through and cooling tower blowdown, (b) ash transport water, i.e. fly ash and bottom ash transport water, (c) metal cleaning wastes, (d) low volume wastes, and (e) material storage run off, i.e. coal pile and ash pile run off. Once-through cooling water systems frequently require addition of chemicals, usually chlorine, to prevent biofouling. Discharge of this effluent has to be controlled to avoid adverse effects on aquatic life. Ash transport water containes total suspended solids, oil and grease etc. which are generally cleaned in the settling pond. However, small amounts of trace metals could be leached and require control if the receiving water body is approaching ambient water quality standards.

The preceding section has focussed on the water (thermal and chemical) pollution involved with the processes of a thermal power plant, highlighting the water cooling systems available to control thermal discharges. In most cases, costs were not available, since they are generally included in the initial investment, but the environmental impacts of each system have been discussed in some detail. Water pollution remains rather difficult to quantify, given the site-specificity of the data requirements. To attempt to impute a value to the water pollution, the data requirements would include (i) current discharge levels (of pollutants) from the plant,

(ii) the current pollution levels of the receiving water body, (iii) the knowledge of mixing patterns of the pollutants, (iv) the impact of all pollutants on each of the species present in the water body.

While discharge levels into and background pollution levels of the water body can easily be computed, the other two requirements related to the mixing patterns and impact are virtually impossible to compute. The mixing pattern is essential to determine the concentration of the pollutants within the water body and, hence, the dosage received by the aquatic species. Mixing patterns are not uniform within a water body; some might accumulate towards the banks while others might be uniformly dispersed. Once the mixing pattern is known, specie distribution within the water body would have to be ascertained in order to estimate the species exposed to the specific pollutant. This would determine the dosage received. By computing the proportion inhaled, ingested and dermally absorbed, the impact of pollution can be determined. Since this would not be possible to achieve practically, costs of treating water prior, so as to meet the effluent discharge standards set by the CPCB, could be used as reasonable approximations of the cost of control of water pollution.

4.4 Indraprastha Power Station Case Study

The Indraprastha (I.P.) Power Station of the Delhi Electric Supply Undertaking (Municipal Corporation of Delhi) is located on the west bank of river Yamuna in the northern part of New Delhi, about two km. south of Rajghat. The power plant comprises five thermal generating units with an aggregate installed capacity of 284 MW. The rating and year of commissioning of each unit are as follows:

Table 4.3: Rating of units at Indraprastha Power Station, New Delhi

Unit No.	Rating MW	Year of commissioning
1	36.6	1963
2,3 & 4	62.5 each	1967-68
5	60	1971

Source: Delhi Electricity Supply Undertaking (1989).

The plant operates at an average plant load factor (plf) of 65 per cent (average of the 5 units), implying an annual generation of about 1200 million kWh.

4.4.1 Cost of the project

Comprehensive financial data on the initial investment made in the plant and equipment for the first unit of IP was not available. Hence, the Central Electricity Authority (CEA) 1991 norms for investment in plant and equipment were used as the capital cost. This was Rs.23500/kW installed capacity (CEA, 1991). This estimate also includes the cost of an ESP, given that their installation is mandatory.

This total cost has been assumed to be distributed over a four year construction period in the following manner: 20, 40, 30, and 10 per cent in the first, second, third, and fourth year, respectively. Interest during the construction period is assumed at 7 per cent per annum.

The cost calculations have been based on the following:

- life of the power plant is 30 years
- annuitized costs are based on a 12 per cent discount rate
- plant load factor of 65 per cent
- coal consumption (average for 5 units) 0.82 kg/kWh
- fuel oil consumption (average) 30 ml/kWh
- cost of coal Rs.944/t (inclusive of freight charges)
- cost of fuel oil Rs.3152/kl
- O&M costs are 2.5 per cent of the capital cost

The cost of electricity generated using the above data is estimated at Rs.1.77/kWh. In the section below, the uncosted impacts are discussed and quantified to the extent possible.

Land pollution

The power plant requires land for the disposal of solid wastes; primarily ash from the combustion process, i.e. fly and bottom ash. The cost of preparation of the disposal site is assumed to be included in the initial investment. Given that the current disposal site is filled to capacity, the plant incurrs an annual expenditure of Rs. 3 crores to transport the ash to low-lying areas around Delhi for landfilling. This adds Rs.0.019 (Appendix 4.E) to the unit cost of generation. Currently, the quantity of wastewater entering the Yamuna from the ash ponds of the power plant is about 300 KLD

(Kumar et al, 1991). This leads to an accumulation/contamination of toxic metals in the river at the rate of 21 kg per day. Table 4.4 gives an analysis of the trace metals in the fly ash effluents from IP.

Table 4.4: Analysis of trace metals in fly ash effluent from Indraprastha Power Station, New Delhi

Metal	Concentration (ug/m^3)
Cadmium	0.001
Chromium	0.260
Nickel	0.347
Iron	68.380
Zinc	0.566
Copper	0.656
Lead	0.533

Source: Kumar, et al, 1991

Given the absence of limits/standards for the discharge of heavy metals, quantification of damages would be necessary in order to impute a monetary value to the pollution. This, however, could not be done since the impact of the pollutants in the Yamuna could not be estimated. Further, the extent of neither leaching from the newly landfilled areas at the outskirts of Delhi nor its degradation has been estimated.

Air pollution

The plant has 3 stacks, each about 61 m high. The 5 units are connected to the stacks in the following manner: Unit I to Stack I, Unit II, III, IV to Stack II, and Unit V to Stack III.

Pollutant dispersion patterns for IP Power Station over Delhi were computed using the TERI Air Quality

Modelling System (TERI, 1990). The model is based on the Gaussian dispersion model and predicts short- and long-term ground level concentrations (GLC) using inputs with regard to the emission source, metereological and other atmospheric data. The results obtained (Appendix 4.C) were used to identify concentrations over some areas of interest in Delhi. Due to short stack heights, pollutant concentrations at ground level close to the plant, i.e. within a 3 km radius, were found to be most significant. However, the proximity of the power plant to several green belts towards the North (Rajghat, Shantivan); dump/waste land tracts towards the South and the Yamuna itself to the East, prevented the exposure of a large population to the pollution.

Short-term average concentrations: The maximum possible pollution downwind of the stack was determined for average wind speeds (2.5 m/s) and unstable atmospheric conditions. The results (given in Appendix 4.D) indicate that the maximum GLC, in terms of plume touching the ground, generally occured within 1 km from the plant. The GLCs for uncontrolled NO_x and SO_x are 140 and 129 ug/m^3, respectively, and 64 ug/m^3 for controlled SPM. SPM concentrations are low because of the assumption of high collection efficiencies (greater than 99.5 per cent) of ESPs. The results are graphed below.

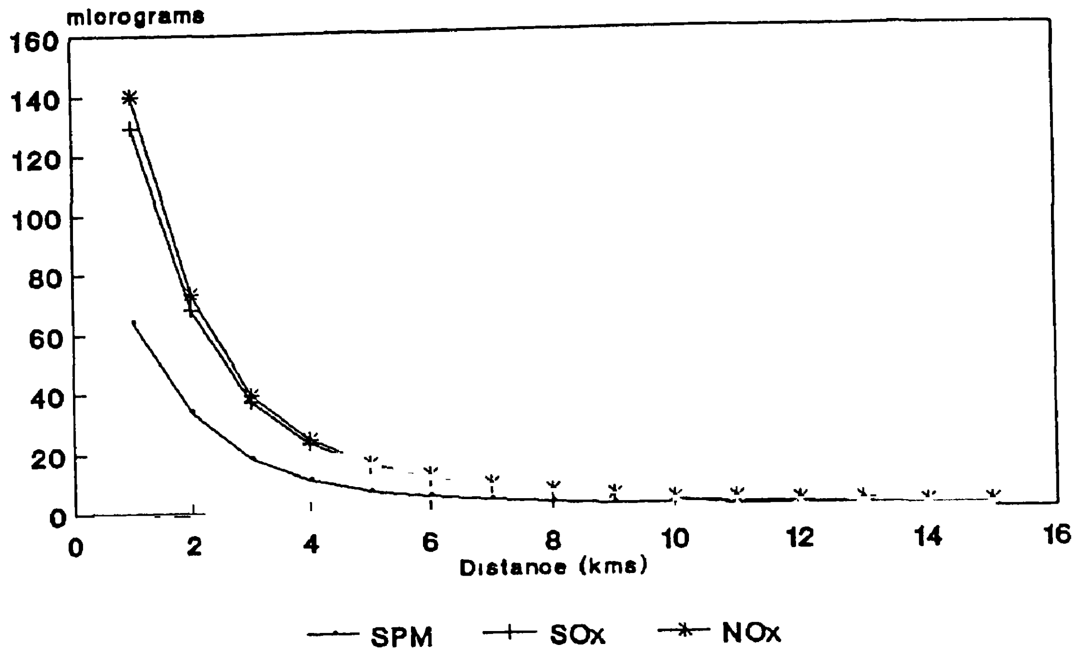


Figure 4.2: Short-term average concentration levels from Indraprastha Power Plant, New Delhi

<u>Long-term seasonal concentrations</u>: The estimation of seasonal concentrations required detailed metereological data such as seasonal wind roses, ambient temperatures, etc. This data was important for the identification of areas most susceptible to air pollution.

Seasonal concentration levels were computed pollutant-wise over some areas in Delhi. Profiles for each area in terms of direction from IP, distance, type of activity, and density of population are given in Table 4.4.

Table: 4.5: Pollution reference areas

Place	Direction	Activity	Distance from plant (kms)	Density of population (per/ha.)
Ram Manohar Lohia Hospital	W	Hospital	4	500
Copernicus Marg	SWW	Cultural	2	400
Rashtrapathi Bhawan	SWW	Residential	5	200
AIIMS	SW	Hospital	6	300
Purana Qila/Zoo	SSW	Historic	1.5	
Sunder Nagar	S	Residential	4	300
Patparganj	E	Residential	5	450
Vivek Vihar	NEE	Residential	4	500
Shahadara	NE	Residential	5	450
ITO/Bahadur Shah Zafar Marg	NW	Commercial	1	450
G.B. Pant Hospital	NW	Hospital	2	500
Connaught Place	NNW	Residential/ Commercial	3	400

The results of the seasonal concentrations of SPM, SO_x and NO_x for the 12 areas have been graphed in Figures 4.3 to 4.6. One result worth mention at this point is that despite its proximity to the plant, Bahadur Shah Zafar Marg did not receive any pollution (as indicated by GLCs) during the 4 seasons; though G.B.Pant Hospital, only a kilometre further in the same direction, did receive some pollution. The effect of tall buildings (and the pollution thereof) has not been estimated in the study.

However, during certain adverse atmospheric conditions, pollution levels in the surrounding areas may be high.

<u>Winter</u>: For the most part of the season, atmopsheric conditions were stable implying low ground level concentrations. The predominant wind directions were ESE and SE. The seasonal average of GLCs ranged from 0-5 ug/m^3. However, instantaneous doses during the trapping period were substantially higher (refer Appendix 4.B). The study assumes that trapping conditions existed for 30 per cent of the season.

Copernicus Marg and Vivek Vihar were identified as the areas receiving the maximum pollution due to SO_x (5 ug/m^3 and 4 ug/m^3, respectively) and NO_x (5 ug/m^3 in both cases). Old Fort received 3 ug/m^3 of all the three pollutants.

<u>Summer</u>: With unstable atmospheric conditions accompanied by high wind speeds of 3.1 m/s, the GLCs were high. The predominant wind directions were ESE and SE.

Both No_x and SO_x concentrations were 5 ug/m^3 each at Copernicus Marg and Connaught Place; 5 ug/m^3 and 2 ug/m^3 respectively at Patparganj; and 3 and 4 ug/m^3 respectively, at Vivek Vihar.

<u>Monsoon</u>: Atmospheric conditions were mainly neutral. The predominant wind directions were WSW and W. Maximum concentration levels (10 ug/m^3 for NO_x) for the localities of interest was recorded during this season [a point to be

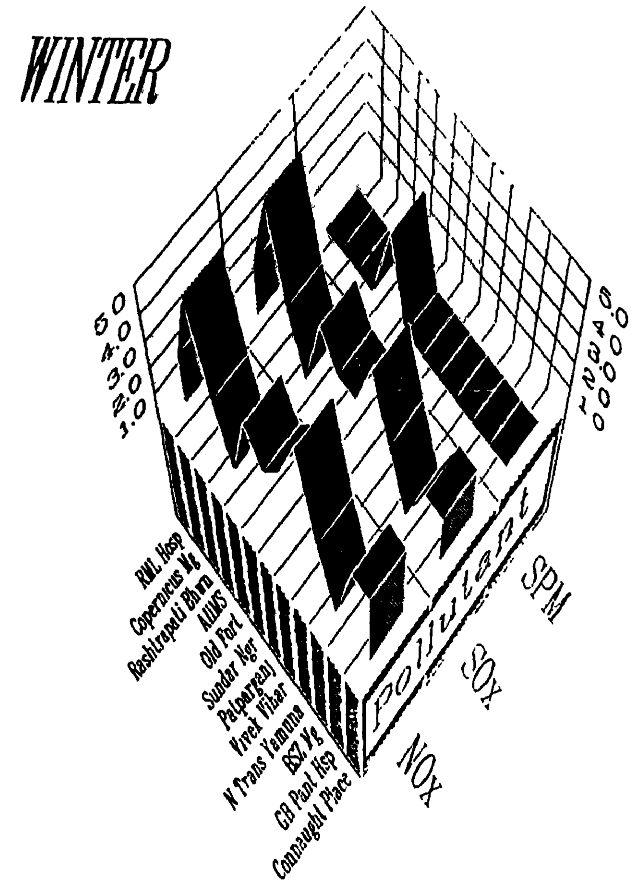


Figure 4.3: Long-term seasonal concentration of pollutants (winter) from Indraprastha Power Plant, New Delhi.

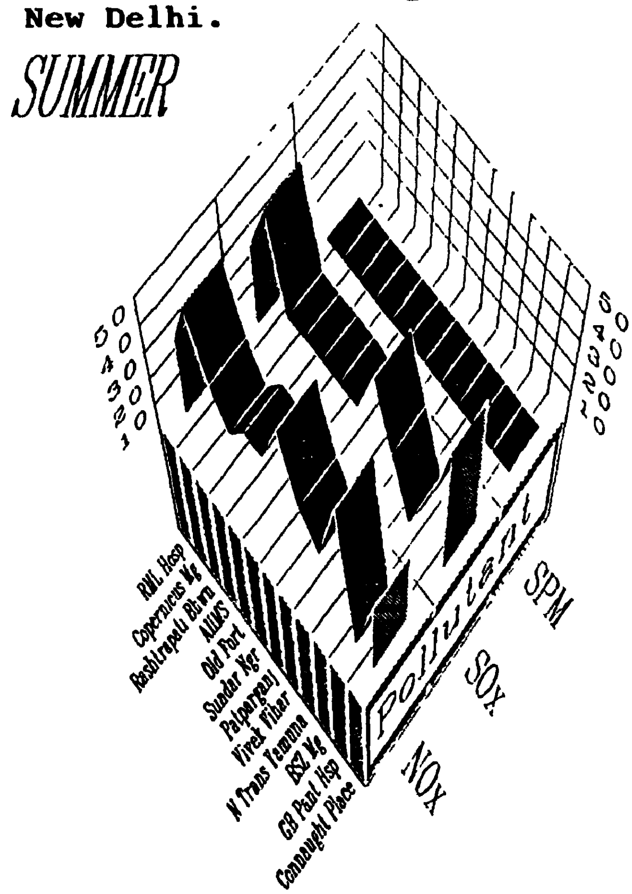


Figure 4.4: Long-term seasonal concentration of pollutants (summer) from Indraprastha Power Plant, New Delhi.

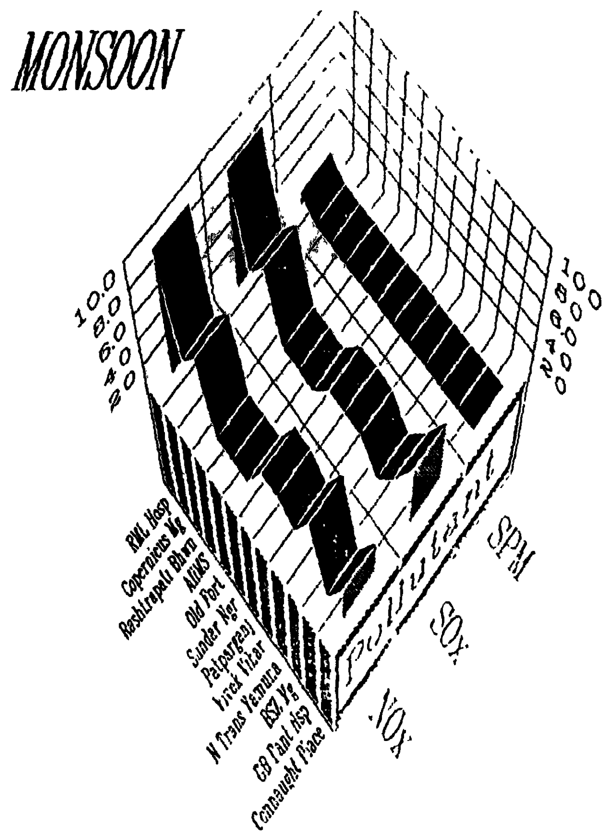


Figure 4.5: Long-term seasonal concentration of pollutants (monsoon) from Indraprastha Power Plant, New Delhi.

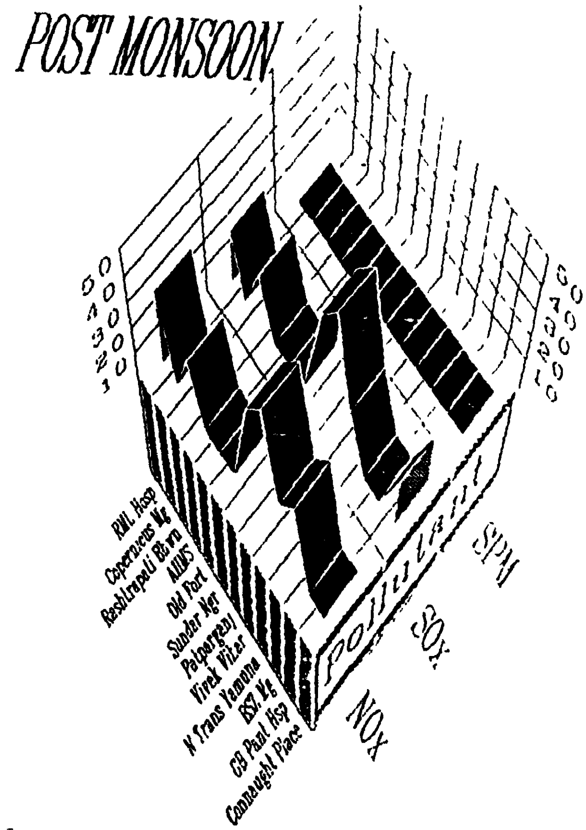


Figure 4.6: Long-term seasonal concentration of pollutants (post-monsoon) from Indraprastha Power Plant, New Delhi.

noted is that higher levels are recorded in winter and summer (30 ug/m^3), but these are confined to the green belts; see Appendic 4.C].

The most polluted area during the season was Ram Manohar Lohia Hospital with 10, 9 and 1 ug/m^3 of NO_x, SO_x and SPM respectively. This was followed by Rashtrapati Bhawan and Connaught Place with 5 ug/m^3 of both NO_x and SO_x. Several regions south of the plant recorded zero concentration levels.

<u>Post Monsoon</u>: Here again, the atmospheric conditions were primarily neutral. Wind directions were predominantly ESE and SE. Pollution levels were generally low with only some areas registering any significant level of pollution.

The principal regions polluted during this season were Vivek Vihar (5 ug/m^3 of both SO_x and NO_x) and Patparganj (4 ug/m^3 of both SO_x and NO_x). Connaught Place recorded 3 and 2 ug/m^3 of NO_x and SO_x respectively.

Given the negligible emission levels of both SO_x and NO_x from the plant and the high costs of FGD and SCR systems, the installation of either is not recommended. This primarily stems from the fact that enforcing such high costs on a marginal emitter cannot be justified.

<u>Water pollution</u>

The plant uses a once-through cooling system, without a treatment plant prior to discharge. It is estimated that, on an average, the temperature of discharge water is around 10°C higher than intake water. This clearly

exceeds the Central Pollution Control Board's (CPCB's) standard of a maximum permissible rise in temperature of 5°C. Given the size of the receiving body and no other plants in the near vicinity, the thermal effect might be diluted. Nevertheless, given low existing levels of dissolved oxygen (DO), sometimes as low as 0.8 mg/l, even slight thermal pollution may have serious consequences, since high temperatures are associated with low DO levels. This problem is likely to be further exacerbated in the summers.

The major source of pollution of the Yamuna is the leaching (300 KLD) that takes place from the ash disposal sites. The wastewater produced as a result of the hydraulic transportation of ash (fly and bottom) from the plant to the disposal site and the subsequent runoff is substantial.

Discharge water from the plant is monitored daily. Chemical analysis of one of the readings (the only one made available) showed that less than 1 mg/l of free available chlorine (as against the standard of 0.5 mg/l) and 2 mg/l of total chromium (against the permitted 0.2 mg/l) were discharged into the Yamuna. This single reading of excessive discharge of pollutants into the receiving water body is not conclusive but indicative of chemical pollution.

The lower bound of the cost involved in preventing chemical pollution could be the cost of chlorination.

Conversely, costs of demineralizing the water would be the upper limit and, in most cases, unnecessary. Thus the cost of treatment would lie between these two bounds. Cost of chlorination of intake water has been estimated at Rs.0.01/kWh (Appendix 4.E). Control of thermal pollution would necessitate installing cooling towers or increasing the size of the condenser. Both options are exceedingly expensive and hence their technoeconomic viability (with due weightage for environmental considerations) would have to be established.

4.4.2 Results

From the above, the cost of generation from the IP power plant is Rs.1.8/kWh. This estimate, however, does not account for (i) leaching from ash dump sites, (ii) deterioration in soil quality at dumping site, (iii) health impacts of the smaller sized particulate, and (iv) water pollution - both thermal and chemical. If methods to compute these externalities emerge, the cost of generation can be expected to increase.

APPENDIX 4.A

Pollutant Dispersion

Using the Gaussian model (described in Appendix 4.B) and a wind rose of the area, ground level concentrations in 16 wind directions around the plant can be determined on a seasonal basis. With the help of a population map of the surrounding areas, the corresponding pollutant concentration levels over various residential/commercial areas affected by the plant can be estimated. However, the actual mapping of pollutants onto the population is an exceedingly complex task and is dependent on a variety of factors.

The population surrounding a power plant are exposed to toxic emissions by three general routes: inhalation, ingestion, and dermal absorption. However not all of these intake modes are of equal importance for a given pollutant.

To calculate the surrounding population exposure to the emissions from the power plant, the surrounding area can be divided into population subregions. These subregions will then form the basis for all exposure calculations. All members of a population group within a subregion are assumed to have the same exposure rates. Accordingly, mean pollutant concentrations and deposition rates need to be determined by subregion for many of the exposure calculations. The calculations and concentrations are generally based on particular pollutant species. If

exposure rates are determined by species, these can latter be combined within the dose-response calculations.

In calculating inhalation exposure rates, it is necessary to differentiate between gaseous and particulate pollutants. Atmospheric transport are used to calculate concentrations for each form, although one form or the other may be negligible for a particular pollutant. Gaseous and particulate pollutants will also behave differently within the human body. Absorption rates within the lungs may be different, for example, and a fraction of the particulates inhaled may actually be ingested. Pollutant behavior within the lungs is complex and highly variable. As with all exposure pathways, knowledge of pollutant behaviour is essential prior to arriving at reasonable exposure calculations. To clarify and simplify calculations, ingestion exposure can be separated into five categories: (1) atmospheric particulates, (2) drinking water, (3) aquatic organisms, (4) animal products, and (5) vegetable products and exposure rates for each relevant category computed. For many pollutants, consumption of drinking water and aquatic organisms may be the primary exposure routes.

Dermal exposure comes from contact with atmospheric particulates, domestic water supplies, and recreational water. These calculations must be based on assumptions about contact times and exposed body area,

using the appropriate pollutant concentrations in the atmosphere, domestic water supplies, and water at recreational locations in the region.

The risk assessment is then an attempt to determine the net risk to regional populations from chronic health conditions associated with a toxic pollutant. Net risk can be defined as the change in the total regional incidence of health effects associated with a change in pollutant emissions. Thus, calculation of net risk requires determining emission rates, environmental concentrations, and exposure rates for the "background" case and the situation of interest. The exposure rates, converted to equivalent doses, can be used with dose-response models and population data to calculate total and net risk.

Exposure rates are determined as a function of subregion around the power plant and subgroup within the population. Population subgroups may be based on age, sex, health status, or other significant variables. The definition of subgroups, however, should be based on known variations to exposure rate (or pollutant dose) or response to exposure. In other words, division by subgroup may not be worthwhile unless the exposure or health effects data are sufficient to distinguish between the subgroups.

By partitioning the population by subregion and subgroup, two significant variables can be incorporated

into the risk calculations. However, in reality both exposure rates and population characteristics will vary over time. Exposure rates will vary as the power plant changes its (1) capacity factor, (2) pollution control procedures, (3) fuel source, or (4) operating conditions. Changes in the regional environment may also cause exposure rates to vary. Population characteristics will vary over the life of a power plant (or other pollutant source) because of normal demographic processes, including urban development and migration, aging, birth, death, and immigration or emigration.

Although these variations in the risk calculations are to be incorporated into the analysis, it is an exceedingly difficult task. Exposure rates can be predicted over time, but most risk analyses use mean values and assume that regional populations are static in space and time. These assumptions are necessary because most normal dose-response equations are based on lifetime, constant-dose experiments. While exposure rates are generally long term impacts, short term exposures to high concentrations would also have to be determined and incorporated into the analysis.

Hence when undertaking a risk-benefit estimation, these factors are to be considered but are often excluded due to the absence of adequate information, as has been done in this study. Limitations of risk calculations imply that exact risk estimates cannot be developed.

In order to arrive at an estimate of the health impacts of the pollutants emitted, access to adequate information about (1) the operation and characteristics of the power plant and its waste streams; (2) regional geography, geology, hydrology, and meteorology; (3) regional population; (4) the behavior and chronic health effects of the pollutant; and (5) regional production and consumption of animal, vegetable, and aquatic organisms (if relevant); is imperative. No toxic risk assessment can be done without this information, although the level of detail required will differ from one case to another. Given the absence of access to such information, our risk assessment methodology is subject to several limitations.

APPENDIX 4.B

This section describes the model formulation of the TERI Air Quality Modelling System (TERI, 1990).

Meteorological parameters

<u>Wind rose</u>

Wind speed and direction are the basic meteorological parameters which affect the plume rise and transportation of pollutants discharged into the atmosphere from the sources. Theoretical considerations show that the concentrations are inversely proportional to wind speed. In the layer of the atmosphere above the ground, wind speed varies with height. Generally, it increases with height. These two basic wind parameters i.e. speed and direction are expressed in the form of a frequency table or in a wind rose form. A wind rose or frequency table gives the frequency or time with which wind blows with a particular speed and direction. The wind direction represents the direction from which the wind is blowing. Wind rose represents 8 or 16 wind directions with each direction making an angle of 45^{o} or 22.5^{o} with the next. Wind speed is expressed in m/s or kmph.

The wind speeds are divided into four classes described in Table 4.B.1.

Table 4.B.1 : Wind speed classes

Class	Mean wind speed	
	kmph	m/s
I	2.5	0.7
II	7.5	2.1
III	15.0	4.2
IV	25.0	6.9

Wind speed less than 2 km/hr are known as calms. Hence to all wind data is to be added a calm bias correction. The frequency of calms is distributed among the lowest wind speed class for each direction as follows:

$$N_a = \frac{n_w N_c}{N_w} \quad \ldots. (1)$$

Where

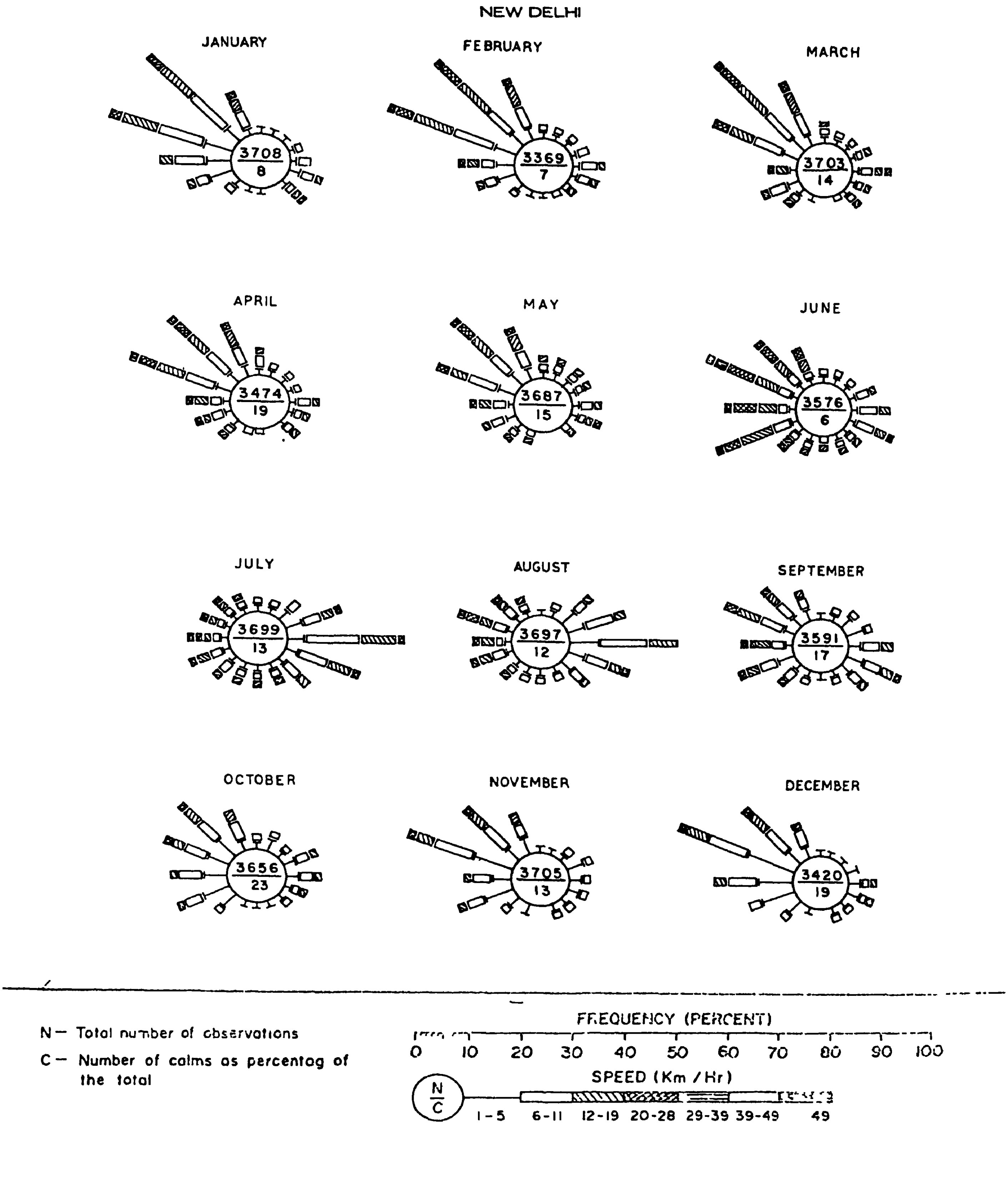
N_a = frequency of calms to be added to a particular direction

N_c = total frequency of calms

N_w = total frequency of the two lowest wind speed classes

n_w = the total frequency of the two lowest speed classes for a particular direction

A wind rose is generally expressed for a month, a season or a year, based on the levels of variation of wind direction. Figure 4.B.1 shows monthly windroses for Delhi.



Source: Agro-climatic atlas of India, India Meteorological Department (1987).

Figure 4.B.1: Monthly windroses for New Delhi

Atmospheric Stability

Atmospheric stability is the term applied to the condition of the atmosphere that affects the vertical motions of air parcels. The atmosphere is said to be unstable when the vertical motion is enhanced. This condition occurs when temperature decreases with height at a rate larger than $0.98^{o}C$ per 100m vertical distance travelled. When the temperature lapse rate (rate of change of temperature with height) equals $0.98^{o}C$ per 100m, the atmosphere is said to be neutral and vertical motions are not affected. This lapse rate is called dry adiabatic lapse rate. When the temperature decreases with height at a rate less than the adiabatic or when temperature increases with height (temperature inversion) vertical motions are damped and the temperature is called stable. Intensity of turbulence and, therefore, the atmospheric diffusion increases with instability of the atmosphere and vice-versa. Atmospheric stability is controlled by insolation, nocturnal radiation loss and wind speed. The following studies have been conducted to formalize the relationships between atmospheric surface stability and those factors controlling stability i.e. insolation, nocturnal radiation and meteorology.

(a) Pasquill stability categories

A classification of stability in accordance with the wind speed and incoming solar radiation for day or cloud cover for night.

(b) Brookhaven stability categories

A classification of stability in accordance with wind direction fluctuations.

(c) TVA stability categories

A classification of stability in accordance with the temperature.

Of the three classifications, the Pasquill method is the most commonly used for the determination of stability class. The Pasquill classification defines six classes of stability. The selection procedure is shown in Table 4.B.2. The basic parameters used for stability analysis are wind speed, insolation and cloudiness. Insolation is estimated by solar altitude and is modified for existing conditions of total cloud cover and ceiling height.

Table 4.B.2: Pasquill Stability Classes

Surface wind speed (at10mt)	Daytime Insolation			Night time condition	
	Strong	Moderate	Slight	Thick overcast or <=4/8 cloud cover	>= 3/8 cloud cover
(1)	(2)	(3)	(4)	(5)	(6)
2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

A - Extremely unstable
B - Moderately unstable
C - Slightly unstable
D - Neutral
E - Slightly stable
F - Moderately stable

Mixing height

The height of the base of the inversion above the ground level is called mixing height (MH). This layer limits the vertical dispersion. If vertical mixing is restricted, the pollutants emitted from a point source into the mixing layer get trapped and, beyond some point downwind, will become uniformly mixed in the vertical. The maximum height of the mixing layer may be estimated from the intersection of the early morning (predawn) temperature profile and the dry adiabat passing through the day time maximum temperature on the temperature height chart (Holzworth G.C 1972). Mixing layer can also be estimated by using a simple model, by knowing the temperatures at different elevations. The model assumes that the environmental lapse rate is a constant. Then,

$$H_m = \frac{T_{max} + C/m}{1/m - 1/m1} \qquad \text{..... (2)}$$

Where

$$C = \frac{T_1 Z_2 - Z_1 T_2}{T_1 - T_2}$$

and

$$m = \frac{Z_1 - Z_2}{T_1 - T_2}$$

H_m = afternoon mixing height, m

T_{max} = maximum temperature of the day °C

T_1 & T_2 = temperatures (°C) at height Z_1 and Z_2 respectively

m_1 = - 100 (reciprocal of adiabatic lapse rate) in m/°C

Z1,Z2 = height above ground level,m

The Gaussian Dispersion Air Quality Model

Basic principle

When discharged to the atmosphere, the emissions from a stationary source are subjected to 1) an initial vertical rise called plume rise, due to initial buoyancy and momentum of discharge, b) transport by wind in its direction, and c) diffusion by turbulence.

Assumptions in the Gaussian Model

a) Steady state conditions, ideal gas, continuous uniform emission rate, homogeneous horizontal wind field, representative mean wind velocity, no directional wind shear in the vertical plane, infinite plume.

b) Total reflection of the plume taking place at the earth's surface.

c) Gaussian distribution, i.e. the pollutant material within the plume takes a Gaussian distribution in both horizontal cross wind and vertical directions.

Basic equation

Concentration in air due to pollutants released into the atmosphere from a single continuous point source is calculated by Pasquill's relation modified by Gifford as follows:

$$C(x,y,z) = \frac{Q}{2\pi\, \sigma y\, \sigma z\, u} \exp\left[\frac{-1}{2} \left[\frac{y}{\sigma y} \right] \right]^2 \left[\left[\exp \frac{-1}{2} \left[\frac{Z-H}{\sigma z} \right]^2 \right] \exp\left[\frac{-1}{2} \left[\frac{Z+H}{\sigma y} \right]^2 \right] \right] \quad \ldots. (1)$$

C(x,y,z) = concentration of the pollutant at receptor point x, y, z from a continuous source, gm/m3

Q = emission rate of pollutant, gm/s

u = wind velocity along the x direction, m/s

y = cross wind distance, m

x = down wind distance, m

z = vertical height, m

H = effective stack height (hs+dh), m

σy = horizontal dispersion coefficient, m

σz = vertical dispersion coefficient, m

hs = stack height, m

ds = plume rise, m

The following sections describe the diffusion co-efficient, wind scaling correction, plume rise, stack downwash and chemical reactions which are a part of the model.

Dispersion coefficients

Dispersion coefficients σy and σz are standard deviations of distributions of concentrations in horizontal cross wind and vertical directions respectively. These

are dependent on the atmospheric stability and the downwind distance. The quantities σy and σz increase with increasing downwind distance x, signifying that the dilution increases with distance. The rate at which σy and σz increase will depend upon the turbulence intensity, and hence stability of the atmosphere. There are three models in use for estimation of dispersion coefficients they are Pasquill -Giffords, TVA, and ASME. In the present study ASME model is used for estimation of dispersion coefficients. This model has four stability classifications viz. a) very unstable b) unstable c) neutral and d) stable.

The standard deviation σy and σz are given in terms of the power law i.e.

$$\sigma y = ax^{p} \quad \ldots\ldots (2)$$

$$\sigma z = bx^{q} \quad \ldots\ldots (3)$$

Table 4.B.3 gives the values of a,b,p,q for the four cases.

Table 4.B.3: Values of a,b,p,and q in the ASME model

Stability	a	b	p	q
very unstable	0.4	0.91	0.4	0.91
unstable	0.36	0.86	0.36	0.86
neutral	0.32	0.78	0.22	0.78
stable	0.31	0.71	0.06	0.71

The averaging time for the dispersion coefficients in the ASME method is one hour.

Scaling of wind speed (Wind speed at stack height)

In the layer of the atmosphere above the ground, wind speed varies with height. Generally it increases with height, but is strongly dependent upon the stability condition of the atmosphere. The wind speed at the stack height was computed based on following power law:

$$U1 = U2(Z1/Z2)^{p} \qquad \ldots\ldots (4)$$

where

U1 = wind speed at height Z1 above msl, m/s

U2 = wind speed at height Z2 above msl, m/s

Z1 = stack height, m

Z2 = elevation of meteorological station above msl, m

p = wind profile component

The exponent p is dependent on atmospheric stability and has a value between 0 to 1. Table 4.B.4 shows recommended values of the exponent p.

Table 4.B.4: Wind speed profile exponent as a function of stability

Pasquill stability class	A	B	C	D	E	F
p	0.15	0.17	0.20	0.26	0.39	0.48

Plume Rise

The plume rise, given by the elevation of the plume centre line above the stack outlet, depends upon the initial flux of momentum (exit velocity) and heat

passing through the stack exit. Over 20 plume rise equations have appeared in literature so far and new ones are proposed annually. For this study, the plume rise equation recommended by I.S.I has been used.

$$Qh = Qm(Ts-Ta)Cp. \qquad \ldots\ldots (5)$$

For $Qh \geq 10^6$ cal/sec

$$dh = 0.84 * (12.4 + 0.09H) * Qh^{0.25}/U. \qquad \ldots\ldots (6)$$

Otherwise,

$$dh = 3\ Ve\ D\ /\ U \qquad \ldots\ldots (7)$$

Where

Qm = emission rate, gm/sec

Ts = efflux temperature, ^{o}K

Ta = ambient temperature, ^{o}K

Cp = specific heat capacity, cal/gm ^{o}K

H = physical height of the stack, m

U = wind speed at stack height, m/s

Ve = efflux velocity, m/s

D = stack diameter, m

Cp is taken as 0.255 for oil, 0.265 for natural gas, and 0.255 for coal.

Stack downwash

When the plume meets an obstacle (natural or manmade), the obstacle seperates the flow thereby generating turbulence in its wake. A cavity is formed behind the obstacle in which the pollutants gets entrained causing concentrations to build up in the cavity. Such an

effect is called stack downwash. The downwash of a plume into the low pressure region in the wake of a stack can occur if the efflux velocity is very low. The effects of a stack downwash are incorporated into the expression for the plume rise by multiplying by a factor `f'. For this study, the downwash correction factor f was computed as per the guidelines set by Cramer et al(Patil S.B. 1984).

$f = 1$ if $u \leq v_e/1.5$ ...... (8)

$f = 3 \times v_e - u/v_e$ if $v_e/1.5 \leq u < v_e$ ...... (9)

$f = 0$ if $u \geq v_e$ ..... (10)

where v_e is efflux velocity in m/sec and u is wind velocity at stack height.

The calculated plume rise is multiplied by the factor f and then used in the dispersion calculation. In this study it was determined that f = 1 for all stacks since Ve>>Us. Thus, due to the exceedingly high exit velocity, there is no possibility of stack downwash.

<u>Chemical reaction</u>

Oxides of nitrogen undergo chemical reactions and the concentration expression should be multiplied with the term

$CR = \exp(-0.693x/uT_{1/2})$ ...... (11)

where

x is the downwind distance

$T_{1/2}$ is the chemical half life of the pollutants.

The average life time for NO_x in urban air is 5 to 8 hours, under day light and sunny conditions with moderate photochemical smog (Luhar .A.K. 1985). Thus, for microscale predictions of NO_x there is no need to apply a chemical attenuation factor.

Rain washout

Falling drops of precipitation pick up particulate matter and soluble gases vapours. This leads to a depletion of pollutants from the atmosphere. Washout leads to higher deposition rates of the pollutants on the ground than those obtained by dry deposition alone. The depletion of concentration due to washout may be computed by multiplying the concentrations obtained from the air quality model by the washout correction factor (FR).

$$FR = \exp\left[\frac{-\Omega x}{u}\right] \qquad \ldots\ldots (12)$$

$$\Omega = 5.9*10^{-4} Y.r^{0.59} \ (S^{-1}) \qquad \ldots\ldots (13)$$

where

Ω = rain washout coefficient

Y = molecular diffusivity in cm^2/sec of the gas

r = rainfall rate in mm/n

Complex terrain effect

Elevated terrain can significantly affect the downwind trajectory of a plume by disturbing the wind flow field. Also large scale eddies can form in the lee side of

a hill or ridge resulting in increased turbulence and diffusion. In the project region the terrain at the site is relatively flat, with elevations ranging from 0-6 mt above mean sea level (msl).

<u>Short term concentrations</u>

The short term concentrations are estimated by equation 1.For concentrations calculated at ground level (z = 0) and at plume centre line (i.e. y = 0) the expression becomes

$$C(x,0,0) = \frac{Q}{\pi\, \sigma y\, \sigma z\, u} \exp\left[\frac{-1}{2}\left[\frac{H}{\sigma z}\right]\right]^2 \quad \ldots.(14)$$

The point at which the maximum concentration occurs is

$$x_{max} = \left[\frac{H^2 d}{(b+d)C^2}\right]^{(1/2d)} \quad \ldots\ldots (15)$$

where b,c,d are parameters associated with the dispersion coefficients.

The maximum ground level concentration is given by

$$(GLC)_{max} = C(x_{max},0,0) = \frac{Q}{\pi\, \sigma y_{max}\, \sigma z_{max}\, u} \exp\left[\frac{1}{2}\left[\frac{H}{\sigma z_{max}}\right]\right]^2 \ldots(16)$$

The point where the plume boundary (defined as the locii of all points where the concentration has dropped to 10 per cent of that at the centre line) touches the ground is given by the equation :

$$x_g = \left[\frac{H}{2.4477C}\right]^{1/d} \qquad \text{...... (17)}$$

Long term averaging

The long term (seasonal, annual) concentration averages of various pollutants are needed to estimate the effectiveness of air pollution control strategies or to ascertain the impact of projected industrial or residential growth, in compliance with ambient air quality standards. The meteorological factors that are used in the calculation of concentrations are the wind speed, wind direction, and stability class. If there are n wind speed classes, S stability classes and 0 wind directions, then the long term average concentration at a distance x in wind direction 0 is given by

$$C(x,0) = \sqrt{2/\pi}\ \frac{Q}{100(2\pi x/0)} \sum_N \sum_S \frac{f(0,N,S)}{U_n\ \sigma_{ZS}} \exp\left[\frac{-1}{2}\ \frac{H^2}{\sigma^2_{ZS}}\right] \qquad \text{.... (18)}$$

where

f(0,S,N) = the percentage frequency during the period of interest that the wind is from the direction 0, for the stability condition S and the wind speed class n.

U_n = mid value of the wind speed of class N

σ_{ZS} = vertical dispersion coefficient corresponding to stability class S.

0 = is the wind direction

For the case of a limited mixing layer or trapping, the following equation applies for distances

equivalent to or beyond certain distance `xtb' (Stern, 1987). xtb is the distance at which the edge of the reflected plume reaches the ground level. At this location and beyond, the concentration distribution is assumed to be uniform in horizontal and vertical direction, i.e. the box model concept:

$$C(x,0) = \frac{Q * f(0,S,N)}{hi\ U_n\ (2 * \pi * x/0)} \qquad ......(19)$$

where

hi = height of the stable layer under which trapping occurs.

Since the 95 percentile maximum values were to be computed, the above approach was modified by keeping a record of individual concentration values to arrive at 95 percentile values. This was evaluated for each direction and location.

Worst possible scenarios

The worst case is useful in identifying the highest impact that will occur in a given year. Trapping and fumigation are the two worst cases of atmospheric conditions which can lead to episodic conditions.

Trapping: Plume trapping occurs when the plume is trapped between the ground surface and a stable layer above. The following equation is used in estimating concentrations under conditions of trapping

$$C_t(x,y,z,H) = \frac{Q}{2\pi u\ \sigma y\ \sigma z\ u} \exp\left[\frac{-y^2}{2\sigma y^2}\right] s\left[\frac{Z}{\sigma z},\frac{H}{\sigma z},\frac{Hm}{\sigma z}\right] \quad \ldots\ldots (20)$$

where

$$s\left[\frac{Z}{\sigma z},\frac{H}{\sigma z},\frac{Hm}{\sigma z}\right] = \sum_{J}\left[\exp\left[-\frac{(Z + 2JH_m - H)^2}{2\ \sigma z^2}\right] + \exp\left[-\frac{(Z + 2JH_m + H)^2}{2\ \sigma z^2}\right]\right]$$

with $J = 0, \pm 1, \pm 2 \ldots \pm \infty$

where Hm is the height of mixing layer in meters. The summation of infinite series can be terminated for $n = 5$ which is reported to be adequate (Turner, 1970). This equation accounts for multiple eddy reflections from both the ground and the stable layer.

Fumigation: When the ground is being warmed by solar radiation and air flows from a cold to a relatively warmer surface, a surface based inversion may be eliminated by the upward transfer of sensible heat from the ground surface. This situation usually occurs for a short duration around mid- morning. In this situation pollutants previously emitted above the surface into a stable layer will be mixed vertically downwards, when reached by the thermal eddies. In such cases, ground level concentrations can become very high. This process is described as fumigation. To estimate ground level

concentrations under inversion break-up fumigations, one assumes that the plume was initially emitted into a stable layer. Therefore, the σy and σz characteristics of stable conditions must be selected for the particular distance under consideration. An expression for ground level concentration is given below

$$C(x,0,0) = \frac{Q}{1.1\sqrt{2\pi}\ \sigma yf\ Hfu} \qquad \ldots\ldots (21)$$

where

$$\sigma yf = \sigma y + 0.47H$$

and

$$Hf = H + 2.15\ \sigma z$$

Averaging time calibration: Concentrations obtained by using the values of the ASME dispersion coefficients would be valid only for a one hour sampling time, for which σy and σz are also valid. To convert a one hour sampling time into an eight hour sampling time, the following power law function of time ratio has been used

$$c_8/c_1 = (t_1/t_8)^{\alpha} \qquad \ldots\ldots (22)$$

The I.S.I has suggested a value of 0.4 for α. Such a relationship is valid between the range of 3 minutes to 24 hours.

APPENDIX 4.C

Seasonal Emissions

Table 4.C.1: Suspended Particulate Matter

TSP EMISSIONS (I+II+III) WINTER

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	13	9	3	3	5	20	31	31	20	18	5	5	3	0	5	15
2	1	0	0	0	0	1	2	3	1	1	0	0	0	0	0	1
3	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TSP EMISSIONS (I+II+III) SUMMER

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	1	1	0	0	0	3	4	4	3	2	0	0	0	0	0	1
2	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1
3	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TSP EMISSIONS (I+II+III) MONSOON

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TSP EMISSIONS (I+II+III) POST-MONSOON

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.C.2: Sulphur Oxides

SOX EMISSIONS (I+II+III) WINTER

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	13	9	3	3	5	20	31	31	20	18	5	5	3	0	5	15
2	7	5	5	2	4	9	16	22	13	13	5	4	2	2	2	7
3	2	2	2	0	2	4	9	11	7	7	2	2	0	2	2	2
4	2	2	2	0	2	2	5	7	4	4	2	2	0	0	0	2
5	2	2	2	0	0	2	4	7	2	2	2	0	0	0	0	2
6	2	0	0	0	0	2	2	4	2	2	0	0	0	0	0	2
7	0	0	0	0	0	2	2	4	2	2	0	0	0	0	0	0
8	0	0	0	0	0	2	2	2	2	2	0	0	0	0	0	0
9	0	0	0	0	0	1	2	2	2	2	0	0	0	0	0	0
10	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0
11	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0
12	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0
13	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0

SOX EMISSIONS (I+II+III) SUMMER

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	12	9	2	2	6	18	29	29	18	16	6	6	2	0	6	14
2	7	5	2	2	5	9	15	15	9	8	5	2	2	0	2	7
3	5	5	2	2	2	7	10	10	6	5	2	2	0	0	2	5
4	3	2	2	2	2	5	7	7	4	4	2	2	0	0	2	4
5	2	2	2	2	2	4	5	5	2	2	2	2	0	0	2	2
6	2	2	2	2	2	2	4	4	2	2	2	0	0	0	0	2
7	2	2	2	2	2	2	2	2	2	2	2	0	0	0	0	2
8	2	2	0	0	0	2	2	2	2	2	0	0	0	0	0	2
9	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0
10	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SOX EMISSIONS (I+II+III) MONSOON

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	5	3	0	0	0	0	2	2	2	2	0	0	0	0	2	3
3	8	5	2	0	0	2	2	3	2	3	2	2	2	2	2	5
4	9	5	2	0	0	2	2	2	2	2	2	2	2	2	2	5
5	9	5	2	0	0	2	2	2	2	2	2	2	2	2	2	5
6	7	5	0	0	0	0	2	2	2	2	2	0	0	0	2	5
7	7	2	0	0	0	0	2	2	2	2	2	0	0	0	2	5
8	7	2	0	0	0	0	1	2	2	2	2	0	0	0	2	3
9	5	2	0	0	0	0	0	2	2	2	2	0	0	0	2	2
10	5	2	0	0	0	0	0	2	2	2	2	0	0	0	2	2
11	5	2	0	0	0	0	0	2	1	2	0	0	0	0	2	2
12	5	2	0	0	0	0	0	2	0	2	0	0	0	0	2	2
13	5	2	0	0	0	0	0	2	0	2	0	0	0	0	2	2
14	5	2	0	0	0	0	0	2	0	2	0	0	0	0	2	2
15	4	2	0	0	0	0	0	0	0	1	0	0	0	0	2	2

SOX EMISSIONS (I+II+III) POST-MONSOON

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	0	0	0	0	2	3	5	2	2	0	0	0	0	0	2
3	2	2	0	0	0	2	5	5	5	5	2	0	0	0	2	2
4	2	2	0	0	0	2	5	5	5	5	2	0	0	0	2	2
5	2	2	0	0	0	2	5	5	4	4	2	0	0	0	2	2
6	2	2	0	0	0	2	4	5	2	2	0	0	0	0	2	2
7	2	2	0	0	0	2	2	4	2	2	0	0	0	0	2	2
8	2	2	0	0	0	2	2	2	2	2	0	0	0	0	2	2
9	2	2	0	0	0	2	2	2	2	2	0	0	0	0	2	2
10	2	2	0	0	0	2	2	2	2	2	0	0	0	0	2	2
11	2	2	0	0	0	2	2	2	2	2	0	0	0	0	0	2
12	2	2	0	0	0	2	2	2	2	2	0	0	0	0	0	2
13	2	2	0	0	0	2	2	2	2	2	0	0	0	0	0	2
14	2	2	0	0	0	2	2	2	2	2	0	0	0	0	0	2
15	2	2	0	0	0	2	2	2	2	2	0	0	0	0	0	2

Table 4.C.3: Oxides of Nitrogen

NOX EMISSIONS (I+II+III) WINTER

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	13	9	3	3	5	20	31	31	20	18	5	5	3	0	5	15
2	5	5	5	2	5	10	17	25	14	13	5	5	2	3	3	5
3	3	2	2	0	2	5	8	12	7	7	2	2	0	2	2	3
4	2	2	2	0	2	3	5	8	5	5	2	2	0	0	0	2
5	2	2	2	0	0	2	5	5	3	3	2	0	0	0	0	2
6	0	0	0	0	0	2	3	5	3	3	0	0	0	0	0	0
7	0	0	0	0	0	2	3	5	2	2	0	0	0	0	0	0
8	0	0	0	0	0	2	2	3	2	2	0	0	0	0	0	0
9	0	0	0	0	0	0	2	3	2	2	0	0	0	0	0	0
10	0	0	0	0	0	0	2	3	2	2	0	0	0	0	0	0
11	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0
12	0	0	0	0	0	0	2	2	1	0	0	0	0	0	0	0
13	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0

NOX EMISSIONS (I+II+III) SUMMER

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	13	9	3	3	5	20	31	31	20	18	5	5	3	0	5	15
2	8	5	3	3	5	10	16	16	10	8	5	3	2	0	3	8
3	5	5	3	3	3	8	10	10	5	5	3	3	0	0	3	5
4	3	3	3	3	3	5	8	8	5	5	3	2	0	0	2	5
5	3	3	2	2	2	5	5	5	3	3	2	2	0	0	2	3
6	2	2	2	2	2	3	5	5	2	2	2	0	0	0	0	2
7	2	2	0	0	2	2	3	3	2	2	2	0	0	0	0	2
8	2	0	0	0	0	2	3	3	2	2	0	0	0	0	0	2
9	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0
10	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOX EMISSIONS (I+II+III) MONSOON

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	6	3	0	0	0	0	3	3	3	3	0	0	0	0	3	3
3	9	5	1	0	0	1	3	3	3	3	3	1	1	1	3	5
4	10	5	2	0	0	2	3	3	3	3	3	2	2	2	3	5
5	10	5	2	0	0	2	2	3	3	3	2	2	2	2	3	5
6	8	5	0	0	0	0	2	3	2	3	2	0	0	0	3	5
7	8	3	0	0	0	0	2	3	2	3	2	0	0	0	3	5
8	8	3	0	0	0	0	0	2	2	2	2	0	0	0	3	3
9	5	3	0	0	0	0	0	2	2	2	2	0	0	0	3	3
10	5	3	0	0	0	0	0	2	2	2	0	0	0	0	3	3
11	5	3	0	0	0	0	0	2	0	2	0	0	0	0	2	3
12	5	3	0	0	0	0	0	2	0	2	0	0	0	0	2	3
13	5	3	0	0	0	0	0	2	0	2	0	0	0	0	2	3
14	5	3	0	0	0	0	0	0	0	2	0	0	0	0	2	3
15	4	3	0	0	0	0	0	0	0	0	0	0	0	0	2	3

NOX EMISSIONS (I+II+III) POST-MONSOON

KM	W	SWW	SW	SSW	S	SSE	SE	SEE	E	NEE	NE	NNE	N	NNW	NW	NWW
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	0	0	0	0	3	3	5	3	3	0	0	0	0	0	3
3	3	3	0	0	0	3	5	6	4	4	1	0	0	0	3	3
4	3	3	0	0	0	3	5	5	5	5	2	0	0	0	3	3
5	3	2	0	0	0	3	5	5	4	4	2	0	0	0	2	3
6	3	2	0	0	0	3	5	5	3	3	0	0	0	0	2	3
7	3	2	0	0	0	2	3	4	3	3	0	0	0	0	2	2
8	2	2	0	0	0	2	3	3	3	3	0	0	0	0	2	2
9	2	2	0	0	0	2	3	3	3	3	0	0	0	0	2	2
10	2	2	0	0	0	2	3	3	3	3	0	0	0	0	0	2
11	2	2	0	0	0	2	3	3	3	3	0	0	0	0	0	2
12	2	2	0	0	0	2	3	3	3	3	0	0	0	0	0	2
13	2	2	0	0	0	2	3	3	3	3	0	0	0	0	0	2
14	2	2	0	0	0	2	3	3	2	3	0	0	0	0	0	1
15	2	2	0	0	0	2	3	3	2	3	0	0	0	0	0	0

APPENDIX 4.D

Table 4.D.1: Downwind unstable conditions

TSP DOWNWIND/UNSTABLE/AVERAGE WIND(2.5M/S)

KM	
1	0.000064
2	0.000034
3	0.000018
4	0.000011
5	0.000007
6	0.000005
7	0.000004
8	0.000003
9	0.000002
10	0.000002
11	0.000001
12	0.000001
13	0.000001
14	0.000001
15	0.000001

SOX DOWNWIND/UNSTABLE/AVERAGE WIND(2.5M/S)

KM	
1	0.000129
2	0.000068
3	0.000037
4	0.000023
5	0.000015
6	0.000011
7	0.000008
8	0.000006
9	0.000005
10	0.000004
11	0.000003
12	0.000003
13	0.000002
14	0.000002
15	0.000002

NOX DOWNWIND/UNSTABLE/AVERAGE WIND(2.5M/S)

KM	
1	0.000140
2	0.000073
3	0.000039
4	0.000024
5	0.000016
6	0.000012
7	0.000009
8	0.000007
9	0.000005
10	0.000004
11	0.000004
12	0.000003
13	0.000003
14	0.000002
15	0.000002

APPENDIX 4.E

Cost Calculations

210 MW plant

(Rs. at 1990-91 prices)

	Land/civil/plant construction	Interest during construction
Year 1	1.3E+09	3.6E+08
Year 2	2.7E+09	4.9E+08
Year 3	2.0E+09	2.1E+08
Year 4	6.7E+08	2.3E+07
	6.7E+09	1.1E+09

Total investment
in commissioning year 7.8E+09

	Rs. at 1990-91 prices
Annualised Capital Cost	9.6E+08
O&M Cost (2.5% of capital)	1.7E+08
Annual Cost of Water	3.3E+08
Annual Cost of Coal	1.3E+09
Annual cost of Fuel oil	1.5E+08
Annual Expenditure	2.9E+09
Annual Generation (kWh)	1.6E+09
Cost per unit generated	1.77314

Table 4.E.1: Cost of generation

Cost of generation (including ESP)	Rs.1.77 per unit
Cost of landfilling (excluding leaching)	Rs.0.019 per unit
Cost of water treatment (chlorination)	Rs.0.01 per unit
Total cost (monetary value)	Rs.1.779 per unit
Cost of FGD	Rs.0.40 per unit
Cost of SCR	Rs.0.12 per unit
Outer bound of cost (without land and water pollution control measures)	Rs.2.32 per unit

CHAPTER 5

Conclusions and Recommendations

Results of the study indicate that the cost of generating a kWh ranges from Rs.0.18-Rs.0.24 for Bhakra Nangal Hydroelectric project; Rs.2.04-Rs.2.89 for a 235 MW CANDU nuclear plant and Rs 1.8-2.32 for the coal based Indraprastha Power Station. It is quite obvious from the results that of the three options considered in this study, hydroelectric generation is the most economic option. The lower limit of Rs.0.18/kWh does not include the social and environmental costs associated with this mode. Taking liberal values for rehabilitation and loss of forests, the upper limit for this option is Rs.0.24/kWh, which increases the costs by 33%. This range is based on the conventional division (as given by BBMB) of costs into the power and irrigation components. However, if there was no irrigational dimensions to the project, i.e. the project consists of only the dam for power generation purposes, the relevant cost range works out to be Rs.0.37-0.43/kWh.

The next best option is coal based power. The actual estimate of Rs 1.8/kWh includes the installation of an ESP. The second estimate of Rs 2.32/kWh includes the extreme case of both a FGD and a SCR. This is most likely an upper bound for the cost.

The economics of generating power from the nuclear option reveals that the lowest possible cost is

Rs.2.04/kWh, provided the plant is constructed in 9 years and has an utilisation of 67%. This includes a decommissioning cost of Rs.0.22/kWh. The higher estimate of Rs.2.89/kWh reflects gestation periods of the past (i.e. 15 years), a utilisation of 47%, based on the present performance of MAPS, and a decommissioning cost of Rs.0.30/kWh.

The above ranges of costs for coal, hydro and nuclear options do not account for the chance of an accident and the likely damages thereof. Of the three options, the damages from an accident at a coal plant can be considered to be minimal; from hydro substantial and nuclear catastrophic. According to the Rasmussen report, the chance of a nuclear accident in a year resulting in more than a thousand fatilities is 10^{-5}, while the same for a dam failure is 10^{-1}.

In light of the various issues identified in the foregoing chapters, the following areas need to be addressed for further research.

Hydro

The low cost for this option which makes it attractive is only valid when displacement and forest loss are kept within certain limits. Rehabilitation of people, when the scale of displacement is very large, may be difficult and is seldom complete, which can seriously affect the lives of the oustees. Similarly, submergence of large areas of forest land, an already stressed resource, is not

affordable. Therefore, it is imperative that upper limits beyond which the project is not considered viable, be defined for both displacement and loss of forests. For instance, upper limits for different forest types need to be defined based on the state of each forest type within the region/country. Past experience on rehabilitation could provide guidelines for establishing limits. To elaborate, perhaps the number and type of people displaced, the areas they are rehabilitated in, might suggest the maximum number that can be satisfactorily rehabilitated. For instance, in the case of tribals or other communities, who are displaced to an altogether different habitat, the permissible levels would be much lower.

Coal

The use of flyash on a large scale is absolutely imperative. Although research is ongoing in this area, there must be an accelerated thrust in developing appropriate cost effective technologies which can make flyash based substitutes economically comparative with current construction materials. To facilitate the supply of dry flyash to entrepreneurs, the power plants would need to have appropriate ash handling systems.

Appropriate siting of a plantcan avoid adding additional pollution control equipment (in the form of a FGD or a SCR). Due to a low sulphur content in Indian coal, unless a plant is already in a stressed locale [e.g.

Vishakapatnam (high SO_x levels) or Singrauli (expected high SO_x levels due to concentration of power plants that will have an ultimate capacity of 18,000 MW)], the use of an FGD under current magnitudes of consumption may not arise. Similarly, plants located away from the metropolitan and major cities may not need NO_x control equipment. Therefore, this aspect should also be included along with other factors that decide plant siting.

Also, standards for heavy metals in ash dump effluents need to be set.

Nuclear

From the results it is obvious that nuclear power generation (of the CANDU type) is the most expensive option out of the three. Even if these plants are constructed and operated with DAE's performance criteria (9 year construction period and plant utilisation of 5500 kWh/kW), the cost of Rs.2.04/kWh generated, is still higher than coal based power generation.

Although, the international estimates for decommissioning have been included in the costing exercise, these may prove to be underestimates, since no reactor has been decommissioned. Plans for decommissioning Indian plants were not available.

The other issue that remains unresolved is long term waste disposal. Realistic estimates of costs for India would provide a more comprehensive evaluation. .pa

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